

The American Mineralogist

*Journal of the Mineralogical
Society of America*

Vol. 33

MARCH-APRIL, 1948

Nos. 3 and 4

Contents

The rôle of temperature in mineralogy.....	M. J. Buerger	101
Mansfieldite, a new arsenate, the aluminum analogue of scorodite, and the mansfieldite-scorodite series.....	Victor T. Allen and Joseph J. Fahey	122
With x-ray notes by.....	Joseph M. Axelrod	133
Second occurrence of brazilianite..	Clifford Frondel and Marie Louise Lindberg	135
Zirconium from the region of Pocos de Caldas.....	R. R. Franco and W. Loewenstein	142
New data on schroëckingerite.....	Howard W. Jaffe, Alexander M. Sherwood and Maurice J. Peterson	152
Presentation of the Roebling Medal of The Mineralogical Society of America to Paul Niggli.....	Edward H. Kraus	158
Acceptance of the Roebling medal.....	Paul Niggli	161
Memorial of Gregori Aminoff.....	Tom. F. W. Barth	166
Memorial of Joseph P. Connolly.....	Louis C. Graton	172
Memorial of Terence Thomas Quirke.....	Carleton A. Chapman	178
Proceedings of the twenty-eighth annual meeting of The Mineralogical Society of America at Ottawa, Canada.....	C. S. Huribut, Jr.	185
Correspondents, fellows, members and subscribers of The Mineralogical Society of America.....		214
Proceedings of Societies: Mineralogical Society (London).....		249
International Geological Congress.....		249
Notes and news: Carbonado from Venezuela.....	Paul F. Kerr, Donald L. Graf and Sydney H. Ball	251
Domestic sources of piezoelectric crystalline quartz.....	Hugh H. Waesche	255
Petrography of a sample of bedrock from a deep well at Rockaway Park, Long Island, New York.....	Claude M. Roberts	258
Nomenclature in mineralogy: the basis for new mineral names.....	Duncan McConnell	260
Unit cell and space group of pirssonite.....	Howard T. Evans, Jr.	261
Note on schirmerite.....	Frans E. Wickman	262



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The enlarged issues of this journal for 1948 are made possible by a grant from the Penrose Fund of the Geological Society of America.

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A journal containing articles on mineralogy, crystallography, petrography, and allied sciences, issued every two months. Contributions are invited from everyone. Office of Publication, Mineralogical Laboratory, Ann Arbor, Mich.

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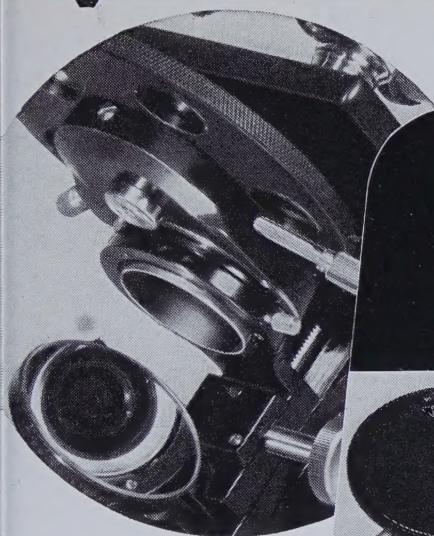
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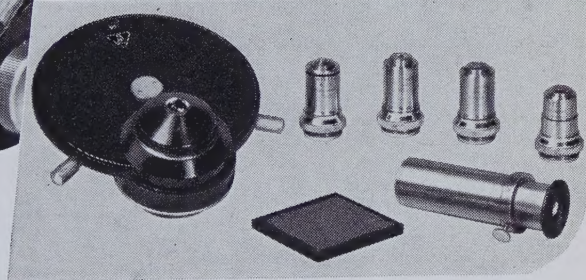
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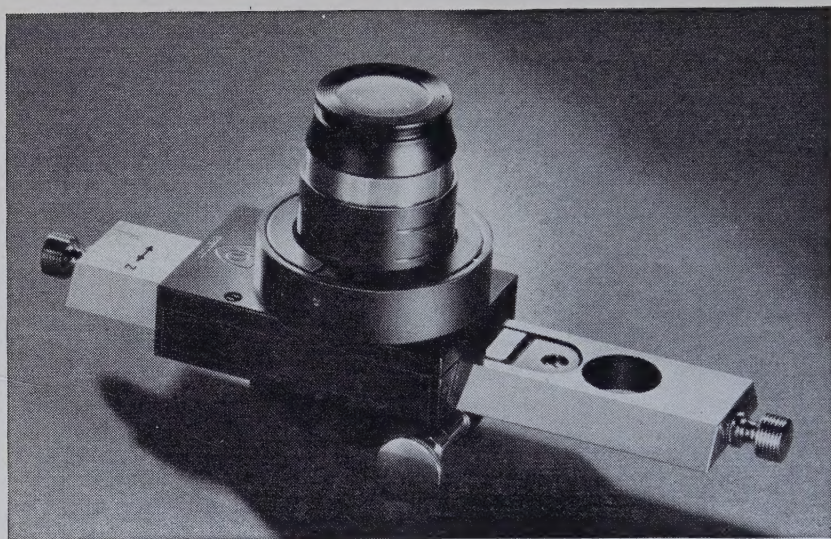
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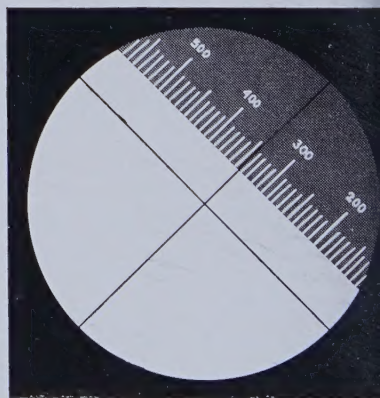
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THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 33

MARCH-APRIL, 1948

Nos. 3 and 4

THE RÔLE OF TEMPERATURE IN MINERALOGY*

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CONTENTS

Abstract.....	101
Introduction.....	102
Polymorphism.....	103
Thermodynamic Background.....	103
Structural Control of Polymorphic Transformations.....	105
The Classical Transformation.....	105
Disordering Transformations.....	108
Disorder and Unmixing.....	111
Diffusion, Disorder and Limited Solid Solution.....	112
Metamorphism and Geochemistry.....	113
General Structural Characteristics and Temperatures.....	115
Coordination Number.....	115
Melting and Reaction Relations.....	116
Some Thermo-Structural Problems of Mineralogy.....	117
The Alkali Feldspars.....	117
The Plagioclase Feldspars.....	118

ABSTRACT

Temperature endows a mineral with energy beyond that of its static crystal structure. This excess energy is the cause of many well-known mineralogical relationships, which can be comprehended as transformations.

Three different structural changes may occur in the transformation of one crystalline phase to another (polymorphism). High-low transformations may be called *displacive* from a structural viewpoint since they correspond with slight displacements of the atoms. Forms connected by displacive transformations always have related symmetries, the high-temperature form having the higher symmetry. Sluggish transformations may be called *reconstructive* since they correspond structurally to destruction of one structure and construction of a new structure from the same units. Changes of coordination number are brought about by a *semi-reconstructive* transformation. Gradual transitions correspond structurally with disordering of the atoms in the structure. Forms connected by gradual transition also have related symmetries.

Disorder is the cause of solid solution. Falling temperature requires ordering. If the crystal which must become ordered is a solid solution, it is necessary for one phase to trans-

* Address of the retiring President of The Mineralogical Society, delivered at the twenty-eighth annual meeting of the Society, Ottawa, Ontario, December 29, 1947.

form into two; in other words, the ordering causes unmixing. Many common minerals, such as the feldspars, have hitherto unrecognized high-temperature forms due to a disorder transition.

Another kind of transformation develops when an energy increase can disrupt *part* of the structural unit. When the character of the structure permits this, a reaction series results. Thus Bowen's reaction series is merely a series of increasingly fragmented silicate units.

Disorder is an important factor in metamorphism. Whenever the temperature is high enough to cause crystal growth (grain growth), it is also high enough to support a sufficient amount of diffusion to render the structure a blotter for certain foreign atoms. The diffusion of these atoms causes a wave of replacement. In a crude way, replacement amounts to a diffusion of the smaller atoms through the interstices of the larger ones. Since the volume of a mineral is dominated by the volume contribution of its larger atoms, replacement tends to occur on an approximately volume-by-volume basis, a characteristic of the process which was empirically discovered by Lindgren many years ago. In metasomatism studies, the oxygen (or other large atom) should be regarded as constant rather than some oxide, such as silica or alumina.

Among the thermo-structural relations which invite further investigation is the entire feldspar problem. The alkali feldspar relations are briefly discussed. It is also pointed out that the natural plagioclases do not constitute a simple solid solution series, but that the low-temperature part of the plagioclase phase diagram must have as end-members, low albite and low anorthite, and that intermediate members are not solid solutions of these end members, but mixtures of them.

INTRODUCTION

The mineralogist is accustomed to think of certain minerals as high temperature minerals and of others as low temperature minerals. He often fixes the general temperature range of deposition of a mineralogical suite with the aid of mineral thermometers. In a similar way, the petrologist knows that certain igneous rock types are of comparatively high temperature origin while others arise at lower temperatures. He also deduces that certain metamorphic events occurred at high temperatures, others at comparatively low temperatures.

Temperature is evidently an important parameter to the geologist. Minerals are the ultimate geological units, and it is obviously desirable that the geologist have an intelligent understanding of the rôle of temperature in the relationships between these units. It is the purpose of this address to bring together some of the more important temperature relationships between minerals, and particularly to show that these relationships can be understood in terms of the structures of the minerals involved. Naturally, in the short time available, the subject cannot be treated exhaustively, so attention will be directed to certain cases which recommend themselves either because of simplicity or geological interest.

Temperature relationships between minerals may be generically regarded as kinds of transformations. This term may be used to cover not

only polymorphism, but also such relations as solid solution, unmixing, reaction pairs in a reaction series, and even some of the relations of metamorphism.

POLYMORPHISM

Thermodynamic Background—The simplest kind of transformation is one involving the change of one crystalline modification into another, namely the polymorphic transition. The general thermodynamic account of the polymorphic transition is well known. Under a given set of conditions, each of the several polymorphic forms of a compound is characterized by an important potential, its free energy. Thermodynamically, a reaction tends to occur which causes a decrease in the free energy of the system. Thus all possible polymorphic forms tend to transform into the one characterized by the minimum free energy. This form is said to be the stable form under the given conditions.

The free energy, A , is the difference between two quantities:

$$A = E - TS, \quad (1)$$

where E is the internal energy, T is the absolute temperature, and S is the entropy. This last quantity is a kind of logarithmic measure of the

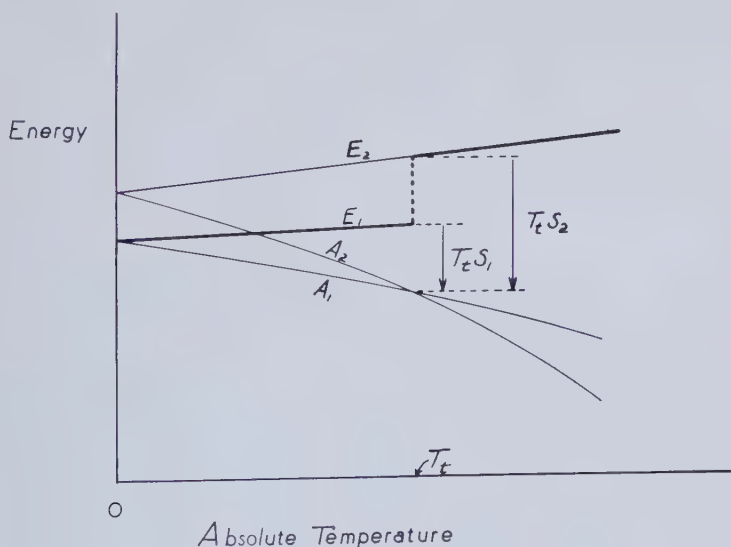


FIG. 1

amount of departure of the crystal from perfect order. Such disorder can be caused not only by departure of an atom from its equilibrium position due to heat motion, but also due to a kind of solid solution.

At absolute zero, the TS term vanishes, and the free energy becomes equal to the internal energy of the crystal, E . Thus, at very low temperatures, the internal energy dominates the free energy, and the polymorphic form with the least internal energy tends to be the stable one. But with increasing temperature the TS term becomes increasingly important, and it may happen (Fig. 1) that, due to the possibility of larger entropy in a second structural arrangement, its TS term so reduces its free energy that, in spite of greater E , the difference between these two terms is greater than that for the first polymorphic form. If this occurs before the first form disintegrates by melting, then the second form becomes the stable one, and the first form tends to transform into it. The temperature at which the free energies become just equal is the transition temperature.

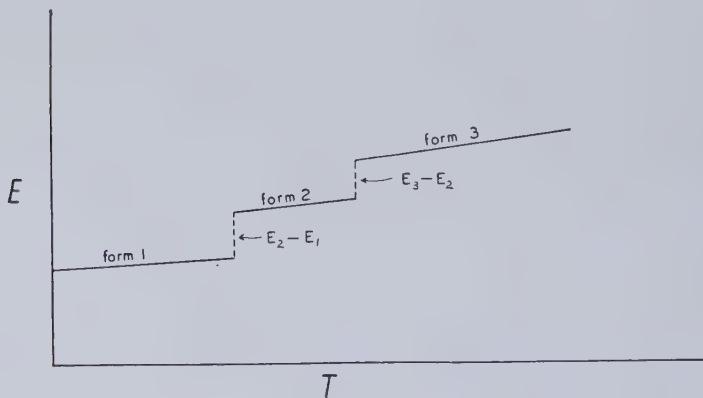


FIG. 2

Note that the second form has a higher internal energy, E , than the first form, and that the difference between the E of the second form and the E of the first form must be supplied to the latter to make the transition occur. This difference is the latent heat of the transition, and, from what has been said, it must be positive for the first transformations. More generally, it can be shown on thermodynamic grounds that it must always be positive in the direction of increasing temperature. For this reason, if one plots the internal energies of a series of polymorphic forms, there results a series of sloping steps, Fig. 2. The significance of this is that a series of polymorphic forms stable at increasing temperatures must have increasing internal energies.¹

¹ Buerger, M. J., and Bloom, M. C., Crystal polymorphism: *Zeits. Krist. (A)*, **96**, 194 (1937).

Conversely, the entropies of a series of polymorphic forms increase for the forms stable at increasing temperatures. Since the entropy involves the volume over which the atoms may be disordered, there is a tendency for the forms of higher entropy to have greater open spaces available for thermal motion. While this does not necessarily involve openness of the entire structure, it often does, so high temperature forms tend to be less dense than low-temperature forms. It should be observed that temperature and pressure tend to impose opposite conditions, for, while high temperature tends to require an open structure, high pressure tends to require a compact one.

Structural Control of Polymorphic Transformations—Polymorphic transitions differ radically in the speed of the transformation. Of course, this depends on the type of barrier opposing the transition. From a structural point of view, the speed of the transformation should depend on the characteristics of the two structures it connects, and on the path of the structure during the transformation. The barrier opposing the transformation and regulating its speed should be represented by the structural bonds which it is necessary to disturb during the transformation.

When the structural barriers are taken into consideration, polymorphic transitions fall into the following classification:

CLASSICAL TRANSFORMATIONS

- Reconstructive
- Semi-reconstructive
- Displacive

DISORDERING TRANSFORMATIONS

- Domain disordering
- Rotational disordering
- Substitutional disordering

The Classical Transformation—A polymorphic transformation classically involves a change from one ordered structure to a different one. (Here, "ordered" disregards the vibrational disorder of thermal motion.) It is characterized by sharp discontinuities in physical properties.

It has been long recognized that two distinct and radically different types of transformation may be involved between the several polymorphic forms and one and the same substance. Sosman has called these² sluggish and high-low transformations. The first is an exceedingly slow transformation while the second is extremely rapid. These very different transformation speeds can be understood by recognizing two different transformation mechanisms:

² Sosman, Robert B., *The Properties of Silica* (The Chemical Catalog Co.), New York, 1927.

There exist polymorphic pairs whose structures are so different that the only way a transformation can be effected is by disintegrating one structure into small units and constructing a new edifice from these units. Such a transformation is appropriately called a *reconstructive transformation*. Examples are the transformation between senarmontite and valentinite, and the transformations between any of the pairs of the set, quartz-tridymite-cristobalite.

A reconstructive transformation requires the breaking of all the first coordination bonds of some small unit (probably the SbO_3 triangle in Sb_2O_3 , and the SiO_4 tetrahedron in SiO_2). The barrier is approximately the heat of vaporization of such a unit. If the vapor pressure of the substance is low, as it is for most minerals at the transformation point, such a transformation may not go on at an appreciable rate unless the mineral is in the presence of a solvent which permits the unit to exchange its bonds in the structure for bonds in the solvent, which then transports the unit to the new structure. This structural transformation obviously corresponds with the phenomenological sluggish transformation.

On the other hand, there exist polymorphic pairs which are structurally so similar that a very slight displacement of the relative parts of one structure serve to transform it into the other without the disruption of any of the first-coordination bonds of the atoms. Mathematically speaking, such polymorphic pairs are topologically equivalent. This kind of transformation may be called a *displacive* transformation. Examples are the high-to-low quartz, and high-to-low cristobalite transitions.

Phenomenologically, the displacive transformation is the high-low transformation. It has some remarkable characteristics. It occurs instantaneously and cannot be delayed because the barrier to transformation is low compared with level of the available thermal energy. It, therefore, occurs spontaneously, and is transmitted as a wave along with the transmission of heat in the crystal. For this reason, it is impossible to preserve the high form by mere quenching. Furthermore, a symmetry relation exists between the high and low forms. The low form always contains some of the symmetry elements of the high form.³ It is because of this that the transformation from the high to the low form frequently gives rise to inversion twins.⁴

The symmetry relationship between polymorphic pairs connected by a displacive transformation is often a useful tool in mineralogical investigation.⁵ One sometimes sees reference to a general rule to the effect that

³ Buerger, M. J., Derivative crystal structures: *Jour. Chem. Phys.*, **15**, 1-16 (1947).

⁴ Buerger, M. J., The genesis of twin crystals: *Am. Mineral.*, **30**, 469-482 (1945).

⁵ Buerger, M. J., and Buerger, Newton W., Low-chalcocite and high-chalcocite: *Am. Mineral.*, **29**, 55-65 (1944).

any high temperature form has a higher symmetry than the corresponding low temperature form. This is not true. The symmetry relation only holds if the pair of polymorphs is separated by a displacive transformation or by an ordering transformation (see beyond).

There is still another type of transformation which occupies a position which is somewhat intermediate between the displacive transformation and the reconstructive transformation. This is here designated the *semi-reconstructive transformation*. With some structural pairs, it is possible to discover a transformation scheme whereby one form may be imagined to be transformed into the other sheet by sheet. Each sheet changes in shape and is sheared relative to neighboring sheets.⁶ The importance of this possible type of transformation appears to depend on whether the structural change in polymorphism involves a change in coordination number or not. When it does, this transformation may be rapid. Where it does not, it appears to be sluggish, and then it is merely a specific mechanism for effecting a reconstructive transformation. This is because the process always requires a change in bonds in the first coordination sphere, and therefore resembles a reconstructive transformation. If a semi-reconstruction transformation is imagined to occur between structures of the same coordination, this scheme requires a change of coordination which implies a disruption of first coordination bonds. This imposes a barrier equivalent to that found in a reconstructive transformation to such changes, and the transformation is accordingly very slow except in metals, where the first coordination actually occurs between an atom and its surrounding electron gas. On the other hand, where the relation between the polymorphs requires a change of coordination anyway, and where this scheme specifically supplies the required change, there is no intermediate barrier, and the transformation may be quite rapid. This is presumably the kind of rather rapid transformation which takes place in iron, cesium chloride and ammonium chloride.

In semi-reconstructive transformations, there is no necessary symmetry relation between the high and low forms. The coordination number, however, changes so that it is ordinarily higher for the low form and lower for the high form. For example, with increase in temperature, there is a change in coordination number from 8 to 6 in the transformation of cesium chloride and similar compounds, from 4 to 2 in tin, and from 12 to 8 in the highest transformation of iron. This coordination change is consistent with low energy, low entropy for the low form, and high energy, high entropy for the high form, as will be pointed out later. The rule is

⁶ Shôji, Hikoroku, Geometrische Beziehungen unter den Strukturen der Modifikationen einer Substanz: *Zeits. Krist. (A)*, **77**, 381-410 (1931).

violated apparently only by the lower structural transformation of iron, which may be complicated by a residue of magnetic features.

Disordering Transformations—Increase in temperature favors increase in entropy and this may involve disorder of all kinds. There are several types of transitions due to disorder other than vibrational disorder, which are connected with such phenomena as ferromagnetism and ferroelectricity. For the most part such transitions are not of direct interest in mineralogy. Rotation is another type of disorder which occurs at elevated temperatures. If a crystal contains tight groups of atoms, thermal agitation can sometimes set such groups into rotation and consequently throw that part of the crystal into rotational disorder. It seems likely that the transformation of calcite at 970° C. observed by Boecke⁷ is of this character, and corresponds with the onset of rotation of the CO₃ group.

While the types of disorder just mentioned are not of much interest mineralogically, there is another type of disorder which is of paramount interest to mineralogists. This is the transformation due to substitutional disorder. This was first suggested for crystals by Tamman,⁸ on the basis of the increase of electrical resistance in Cu₃Au with rising temperature. The matter was confirmed in an x-ray investigation by Johansson and Linde,⁹ but the concept was not generally accepted by physicists until it was popularized by Bragg and Williams.¹⁰ Since then there have been numerous theoretical and experimental contributions to the subject. It should be pointed out, however, that the disorder transformation had already been deduced by mineralogists,¹¹ for such a transformation is required to explain some of the well-known mineralogical cases of solid solution and of unmixing. On the other hand, mineralogists have made comparatively little subsequent use of this transformation in explaining certain features of crystals which are probably more prominent in mineralogy than in any other field.

If a crystal contains two (or more) chemically-different kinds of atoms which play similar rôles in the crystal structure, then, under appropriate thermal conditions, disorder may occur between these atoms, provided that the thermal agitation required does not first decompose the crystal

⁷ Boecke, H. E., Die Schmelzerscheinungen und die umkehrbare Umwandlung des Calciumcarbonats: *Neues. Jahrb. f. Min., etc.*, 1912, I, 91–121, esp. 113–118.

⁸ Tamman, G., Die chemischen und galvanischen Eigenschaften von Mischkristall-reihen und ihre Atomverteilung: *Zeit. Anorg. Chem.*, **107**, 1–239 (1919).

⁹ Johansson, C. H., and Linde, J. O., Röntgenographische Bestimmung der Atomanordnung in Mischkristallreihen Au-Cu und Pd-Cu: *Ann. Physik*, **78**, 439–459 (1925).

¹⁰ Bragg, W. L., and Williams, E. J., The effect of thermal agitation on atomic arrangement in alloys: *Proc. Roy. Soc., A*, **145**, 699–730 (1934).

¹¹ Buerger, M. J., The temperature-composition-structure behavior of certain crystals: *Proc. Nat. Acad. Sci.*, **20**, 444–453 (1934).

by melting it. This phenomenon may be discussed in elementary and general terms as follows:

Suppose a crystal contains, among its many atoms, two, designated **A** and **B**, which occupy similar structural positions in the structure. For example **A** and **B** may be Cu and Fe in tetrahedral coordination in a sulfide, or they may be Al and Si in tetrahedral coordination in a silicate, or they may be Fe and Ti in octohedral coordination in an oxide. Suppose all other atoms in the structure are symbolically represented by **C**. The composition of the crystal is now symbolically represented by **ABC**.

Now the temperature energy of the crystal has an average value of kT , where k is Boltzmann's constant, and T is the absolute temperature. The atoms **A** and **B** are held to their positions by bonds also having definite energy values. If the temperature is high enough to make the thermal energy, kT , comparable with the bond energy, then the thermal energy may occasionally detach an atom from one or more of its bonds and partially free it from its place in the structure. If the structure contains any opening, atoms **A** and **B** may temporarily be ejected into them. This is particularly probable in open structures such as those of some of the tetrahedrally linked sulfides. If neighboring **A** and **B** atoms are simultane-

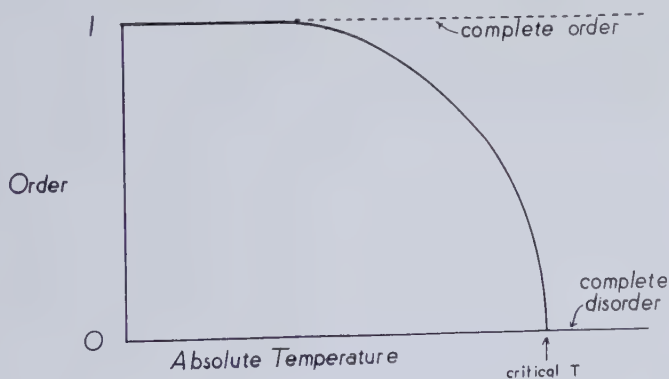
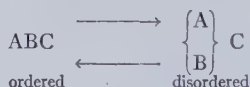


FIG. 3

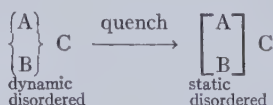
ously ejected from their positions in the structure, they may either return to their original positions, or they may interchange positions provided their motions are correctly directed. If the latter occurs, then this pair of **A** and **B** atoms is in disorder. This increases the energy of the crystal by an amount which will be designated V . (If there were not this energy difference favoring the original structure, it would not have crystallized as an ordered structure.) Two tendencies now oppose one another. The interchange energy, V , tends to favor the return of dis-

ordered pairs to their original positions, and thermal agitation tends to produce disordered pairs. These tendencies are weighted by the Boltzman factor $e^{-V/kT}$. When the number of available interchange sites and the variation of the interchange energy, V , are taken into account, it turns out that there is always a little disorder above absolute zero and the amount increases with temperature. In fact, it increases at a catastrophic rate and becomes complete at a critical temperature which is a characteristic of the structure and composition of the crystal, Fig. 3. This temperature may be regarded as the transformation temperature from the ordered to the disordered state. Above this temperature, **A** and **B** atoms indistinguishably proxy for one another in the structure. Below this temperature, there is a tendency for **A** and **B** atoms to separate into different sets. The separation develops rapidly with temperature-difference below the critical temperature, but does not become absolutely complete until absolute zero is attained.

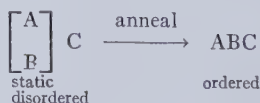
The disorder transformation can be represented in the following way:



Here the braces indicate that the enclosed atoms are in dynamic disorder, *i.e.*, that they are actively interchanging places in the structure. The disorder can be preserved to low temperatures by quenching:



Here the square brackets indicate that the enclosed atoms are in static disorder, *i.e.*, they are not interchanging places, but are frozen in. The quenching occurs because temperature motion alone causes interchange. The static disordered structure can be ordered by annealing at some elevated temperature less than the critical temperature:



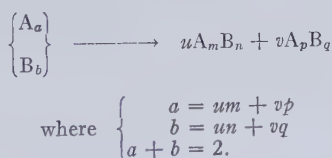
The same symmetry relations exist between ordered and disordered structures as exist between low and high polymorphic forms connected by a displacive transformation. Specifically, the symmetry of the ordered form is a subgroup of that of the disordered form.³ For this reason inversion twinning commonly occurs when a disordered crystal becomes ordered.⁴

DISORDER AND UNMIXING

A mineral capable of disorder can be expected to exist in quite different compositions depending on whether it was deposited above or below the critical temperature of disorder. If the temperature of formation is below the disordering temperature, the structure must reject an excess of **A** or **B** atoms and accept only formulary amounts of **A** and **B**. On the other hand, if the temperature of formation is above the disordering temperature, nothing prevents an excess of **A** or **B** from entering the structure, for the structure does not distinguish between **A** and **B** atoms. With an excess of **A** atoms the composition of the crystal can be represented by

$$\left\{ \begin{matrix} A_{1+x} \\ B_{1-x} \end{matrix} \right\} C, \quad \text{or} \quad \left\{ \begin{matrix} A_a \\ B_b \end{matrix} \right\} C, \quad \text{where } a + b = 2.$$

Consider what happens when this disordered crystal of irrational composition is cooled below its disordering temperature. The structure cannot transform into an ordered structure because this requires the ratio of a to b to be a simple fraction. The atoms can attain order, however, if the disordered crystal decomposes into two ordered crystals. This can occur as follows, in so far as the ordering of **A** and **B** are concerned:



Here a and b are not integers but m and n , also p and q , are integers. Thus the irrational ratio of a to b is transformed into the irrational amounts u and v of the two new ordered crystals. This process, of course, is unmixing, specifically complete unmixing from complete solid solution.

For simplicity, unmixing has been discussed as the extreme case of splitting a completely disordered crystal into two completely ordered ones. This corresponds to having the disordered crystal above the critical temperature and the ordered crystals at absolute zero. Actually, the ordering process covers a range of temperatures, partly because the transformation temperature depends on composition, partly because there is a permissible small amount of disorder at any non-zero temperature.

The unmixed crystal pairs grow in such a relation to one another as to minimize the energy of the new surface of separation. Now, two structures can have a low energy interface if they have a common structural plane. If they have only one common structural plane, the boundary between unmixed structures tends to be planar. For this reason sheet-like

unmixing structures are common. Cubanite in chalcopyrite provides an example. If the two crystals are nearly or exactly isostructural, they have many structural planes in common and the exolved crystal tends to have a bleb-shaped form. Chalcopyrite in sphalerite is an example of such an unmixed form.

Whenever unmixing occurs from a crystal having the compositional form of a double salt, it is an indication that a considerable amount of disorder is tolerated among the metals of the double salt. This suggests a possible disordering transformation in the host mineral involved. Possible examples of the disorder transformation can be inferred from the following examples of unmixing from double salts:

silver	from dyscrasite
cubanite	from chalcopyrite
chalcopyrite	from bornite
pyrrhotite	from pentlandite
chalcopyrite	from stannite
hematite	from ilmenite
albite and anorthite	from labradorite (see beyond)

DIFFUSION, DISORDER AND LIMITED SOLID SOLUTION

The process of ordinary self-diffusion in crystals resembles that of substitutional disorder. It occurs when the thermal energy is sufficient to detach atoms from the bonds to their nearest neighbors. Thus partly freed, the atoms may return to their own places or they may interchange places with their neighbors. The latter instances contribute to diffusion. As is the case of disorder, this type of diffusion may be expected to take place most readily in the more open structures, such as the tetrahedral structures.

In self-diffusion, there is no interchange energy, V , as in the case of disorder, because the diffusing atoms are alike. However, any given level of the thermal energy is capable of supporting a certain amount of disorder. Thus, if impurity atoms are available at the time of the formation of the crystal, they can be tolerated up to the allowed disorder level and are accordingly accepted up to this level by the structure. When the temperature falls, however, this amount of disorder can no longer be thermally maintained, and unmixing ensues provided an appropriate guest structure of low energy exists.

Examples of unmixing from solid solutions which were maintained by thermal diffusion are:

chalcopyrite	from sphalerite
bornite	from chalcocite
millerrite	from lineaites

ilmenite	from hematite
ilmenite	from magnetite
albite	from orthoclase

METAMORPHISM AND GEOCHEMISTRY

I have endeavored to focus your attention more and more sharply on the disordering tendency of temperature. We have seen that the disorder supported by temperature occurs not only as simple vibrational disorder, but also as domain disorder, rotational disorder, and finally substitutional disorder. This last is nothing more than a generalized type of diffusion. This very feature provides the essential mechanism of metamorphism, and more generally, it is the agent of geochemistry.

Metamorphism involves many factors which we cannot consider in any detail. Specifically, it often involves pressure, a discussion of which is outside the range of this discourse. I do wish, however, to point out that the really essential factor in metamorphism is temperature, and that without an adequate temperature level there is no metamorphism.

Consider one of the simplest instances of metamorphism, the matter of the recrystallization and grain growth of a monomineralic rock, such as a limestone. To drive recrystallization, some kind of energy difference is required. This is ordinarily supplied in the form of strain energy consequent upon plastic deformation.¹² The energetics are then somewhat analogous to those involved in a polymorphic transformation. The strained material is, in effect, a metastable polymorph, and the energy difference between the strained and unstrained mineral is the potential which drives the transformation. It is opposed by a structural barrier which prevents the transformation unless temperature provides the required activation energy. During the recrystallization, the crystalline matter at points of greatest strain transforms into small strain-free nuclei. The process probably takes place by essentially a semi-reconstructive transformation. The temperature of recrystallization is known to be lowered with increasing strain energy,¹² but it would not occur at all if it were not for the existence of temperature, for the energy associated with the temperature is required to supply the activation energy necessary for the transformation. Nor would the subsequent growth of crystal dimensions occur in metamorphism unless thermal energy supplied the activation energy necessary to remove atoms from one crystal and implant them on the growing crystal. Thus, no limestone would ever recrystallize at absolute zero, nor would it recrystallize in geologically

¹² Buerger, M. J., and Washken, Edward, Metamorphism of minerals: *Am. Mineral.*, **32**, 296-308 (1947).

available time unless the temperature is above a certain level characteristic of the mineral and its strain. Of course, this is why unmetamorphosed limestones exist in very old rocks.

It is known that the activation energy of grain growth in metals is about twice the activation energy required to make the metal atoms diffuse through their own solid structure.¹³ The reason for this, evidently, is that more bonds must be broken to transport an atom across a crystal boundary than to merely pass it along in the same structure. *There is an important geological significance to this relation, for it implies that whenever the temperature is sufficiently high to cause spontaneous growth of the crystals, it is already maintaining a very high level of diffusion.* In this condition, the smaller atoms, at least, may be expected to be rather freely migrating through the remainder of the structure of the crystal. Thus, whenever the rock is in a condition to recrystallize, it is also something of a blotter for available atoms, thanks to temperature. It is, therefore, evident that wholesale diffusion must play an important rôle in the transfer of chemical material in metamorphism.

Not only must diffusion play an important rôle in metamorphism, but it appears that sulfide replacement in ore deposits is on a similar footing, for such features as unmixing bespeak free diffusion. The process occurs at lower temperatures in sulfides than in the rock minerals because the tetrahedral coordination of sulfur imposes a rather open structure on its minerals. Thus, at moderate temperatures a sulfide can hardly avoid blotting up the atoms supplied to it by the surrounding solutions. As the atoms are passed along, a wave of replacement ensues.

Lindgren long ago pointed out¹⁴ that replacement occurs on approximately a volume-by-volume basis. While the field evidence for this has been obvious, the mechanism for accomplishing it has been obscure. Diffusion suggests the mechanism. There is a tendency on the part of crystals to have their volumes determined by their largest atoms. Thus, the volumes of the rock minerals are dominated by their oxygen atoms and the volumes of the sulfides are dominated by the packing of the sulfur atoms. Replacement is, therefore, substantially a matter of the diffusion of new metals into the volumes dominated by oxygen or sulfur atoms. Thus diffusion supplies a mechanism for approximately maintaining volume during replacement.

In studying metamorphism, it is customary to consider that some oxide, such as silica or alumina, has remained constant while other oxides

¹³ Beck, Paul A., Kremer, Joseph C., and Demer, L., Grain growth in high purity aluminum: *Phys. Rev.*, **71**, 555 (1947).

¹⁴ Lindgren, Waldemar, Mineral Deposits, 3rd edition (McGraw-Hill, New York), p. 798 (1928).

have varied in the process. Evidently a closer approximation would be that the *oxygen* content has remained nearly constant while the wandering interstitial metals themselves have varied with the change.

GENERAL STRUCTURAL CHARACTERISTICS AND TEMPERATURES

Polymorphism is essentially a matter of the variation of structures in a one-component system with temperature (or other conditions). In the discussion of polymorphism, it was seen that certain generalizations could be made in understanding the variation of structure with temperature. Some of these features are of such generality that they can be carried over into a discussion of phase changes in multicomponent systems.

Coordination Number and Temperatures—In discussing the semi-reconstructive transformation in polymorphism, it was pointed out that the higher temperature polymorph tends to have lower coordination. This feature is not peculiar to polymorphism, although it is more obvious in that relation than in more general relationships merely because the variable of chemical composition is held constant. More generally, if an atom can assume several possible coordinations, there is a general tendency for it to display the lower coordination in crystals formed at elevated temperature. In mineralogy, aluminum is well-known to assume coordinations with oxygen of either four or six, perhaps even five, and there is some evidence that different coordinations can also be displayed by iron, boron, and possibly magnesium. In typically high temperature crystals, there is a tendency for aluminum to assume a coordination of four, and in this rôle it often substitutes for silicon. In typical lower temperature minerals, it tends to assume six coordination. The four and six coordination tendencies of aluminum are illustrated in feldspar and the clay minerals, respectively, which are characteristically high and low temperature minerals. Minerals of intermediate temperature affiliations may have both four and six coordinated aluminum, as in the case of the micas.

The general tendency for lower coordinations at higher temperatures appears to be a matter of high entropy coupled with lower internal energy. Atoms in lower coordination are freer to wander over larger volumes, and thus have larger entropies. At the same time, if the bond is electrostatic, and the atom can assume either high or low coordination, the low coordination is the one of high energy. In this way, the free energy

$$A = E - TS$$

is minimized by high coordination at low temperature and low coordination at high temperature.

It might be pointed out that this situation, which has been discussed for the first coordination of an atom, holds for the second coordination

as well, and in an even more obvious form. Thus, in the displacive transformation, the first coordinations of all atoms are constant, but in their higher coordinations, particularly the second coordinations, all atoms move away from one another as the temperature is increased through the transformation point. This provides greater space for thermal motion, thus increasing the entropies of the atoms at the expense of energies of their second coordinations and the energy of bond distortion.

Melting and Reaction Relations—There is an interesting relation between the arrangement of minerals in Bowen's discontinuous reaction series and the order of increased sharing of oxygen atoms by silicon atoms in the silicates. In all silicates, the silicon atom is surrounded by four oxy-

Number of oxygen atoms shared per silicon tetrahedron	Type	Example	Bowen's discontinuous reaction series
0	orthosilicates	olivine	olivine
1	pyrosilicates	mellilite	
2	metasilicates	pyroxene	{ Mg pyroxenes
half 2, half 3	double chain silicates	amphiboles	{ Mg, Ca pyroxenes
3	sheet silicates	micas	{ amphiboles
4	network silicates	quartz	{ biotite
			{ muscovite
			{ quartz

gen atoms in tetrahedral coordination. Each oxygen atom may belong to one silicon atom only or it may be shared between two neighboring silicon atoms. If it is shared, then the oxygen:silicon ratio is reduced, and the formula of the silicate departs from the formula of the pure tetrahedron, namely SiO_4 . Since each silicon tetrahedron may share any number up to four oxygen atoms with its neighbors, several silicate formulae are possible which depart the more from SiO_4 the greater the number of the four possible oxygen atoms shared. The general sharing schemes which have been found by crystal structure studies of the silicates are shown in comparison with Bowen's reaction series, in the accompanying table. The comparison between Bowen's reaction series and the number of shared oxygens in the silicon tetrahedron is striking. What is its significance?

Two factors appear to be involved. In the first place, it must be evident that thermal agitation sufficient to disintegrate a structure of linked tetrahedra must leave fragments of simpler linking. Thus a mica sheet

could conceivably be disintegrated into amphibole double chains, pyroxene single chains, melilite pairs, or single unshared tetrahedra, all plus a residue. In a similar manner any of the linked structures higher in the series can be disintegrated into fragments of structures having less sharing. Thus with increasing temperature the breakdown sequence is networks, multiple chains, single chains, tetrahedron pairs, and single tetrahedra, all plus a residue which appears as a glass. This corresponds very well with Bowen's up-temperature sequence, except for the presence in the theoretical sequence of the pyrosilicates which are absent in Bowen's series.

This is a purely geometrical picture. A bond picture is also involved. As an obvious consequence of Pauling's rules, the number of atoms which bond together the silicate units depends on the number of *unshared* oxygen atoms. Thus, the greater the sharing, the fewer the bonding atoms, the looser the binding of silicate units to one another, per silicon atom, and the lower the temperature of disintegration of the structure.

Consider, now, the effect of aluminum. If the aluminum proxies for silicon in certain tetrahedra, the saturation of the oxygens of those tetrahedra is reduced and they are capable of contributing to stronger bonding between silicate units than without the aluminum. In this way, the presence of aluminum proxying for silicon in a silicate increases its disintegration temperature and consequently raises its position in the reaction series. This is true for both discontinuous and continuous reaction series. The effect of aluminum in a discontinuous reaction pair can be seen in the higher position of leucite (Al:Si=1:2) with respect to orthoclase (Al:Si=1:3). The effect of aluminum in a continuous reaction series is illustrated by the higher position of anorthite (Al:Si=1:1) with respect to albite (Al:Si=1:3).

SOME THERMO-STRUCTURAL PROBLEMS OF MINERALOGY

I conclude my remarks by pointing out the nature of some of the outstanding, yet simple, problems which concern the mineralogist interested in structure. The purely geometrical aspects of the structures of many mineral groups are now fairly well established. The forefront of structural interest has, therefore, moved to the elucidation of some of the more general problems of mineralogy. Chief of these is the clarification and explanation of phase relationships. The relationships between the feldspars may be taken as a typical case. Something is known of these relationships, but much remains to be done before they are truly cleared up.

The Alkali Feldspars—It has been recognized for some time that the alkali feldspars display polymorphism. Thus microcline is triclinic while

the orthoclases, adularia and sanidine, are monoclinic. It is known that prolonged heating transforms adularia slowly into sanidine,¹⁵ but that it has proven more difficult¹⁶ to experimentally transform microcline into sanidine. Barth¹⁷ suggested an explanation for the microcline-sanidine relationship. Expressed in present day language, he postulated that one aluminum and three silicon atoms, which occupy similar structural rôles in the alkali feldspars, are in disorder in sanidine but are ordered in microcline. Since disorder gives rise to statistical high symmetry while order requires reduced symmetry, this accounts for the monoclinic-triclinic feature of the polymorphism. (Incidentally, the Scotch-plaid twinning of microcline is reminiscent of order twinning.)

Barth is less certain about the adularia-sanidine relationship, but he suggests that some aluminum-silicon rearrangement is responsible for this also. If order and disorder among the aluminum and silicon atoms accounts for the microcline-sanidine relationship, as I believe it does, it is easy to understand that the thermal energy required to interchange the silicon and aluminum over the barrier of their oxygen coordination may be too high to allow appreciable experimental conversion of microcline to sanidine. But if this is so, it ought also to prevent the conversion of adularia to sanidine, which is not in accord with the data. An alternative explanation of the change from adularia to sanidine is that it might be concerned with the diffusion of potassium through the somewhat open structure. It is possible that the diffusing potassium atoms might occupy unequivalent voids in sanidine, while they occupy equivalent voids in adularia. This amounts to saying that the adularia-sanidine relationship is concerned with disorder of the alkali, while the microcline-orthoclase relationship is concerned with disorder in the aluminum-silicon content of the feldspar. At the present time, the whole situation is in an unsatisfactory state for lack of data and only further structural studies will clear it up.

The Plagioclase Feldspars—The same state of near-knowledge pervades our understanding of the plagioclase relationships. The plagioclases are usually cited as the classical example of perfect solid solutions. Yet mineralogists have had information for eight odd years indicating that this is not the truth. A mere reconnaissance structural investigation of the plagioclases by Chao and Taylor¹⁸ showed that the relationship is

¹⁵ Barth, Tom. F. W., Permanent changes in the optical orientation of feldspars exposed to heat: *Norsk. Geol. Tidssk.* **12**, 57-72 (1931).

¹⁶ Spencer, Edmondson, The potash-soda feldspars. I. Thermal stability: *Mineral. Mag.*, **24**, 453-494, esp. 480-481 (1937).

¹⁷ Barth, Tom. F. W., Polymorphic phenomena and crystal structure: *Am. Jour. Sci.* (5), **27**, 273-286 (1934).

¹⁸ Chao, S. H., and Taylor, W. H., Isomorphous replacement and superlattice structures in the plagioclase feldspars: *Proc. Roy. Soc. (A)*, **176**, 76-87 (1940).

much more complicated. They found that, while albite has a cell comparable with the sanidine cell, anorthite has a cell twice as high. More astounding, labradorite is not a solid solution of albite and anorthite, but a composite mixture of albite and anorthite.

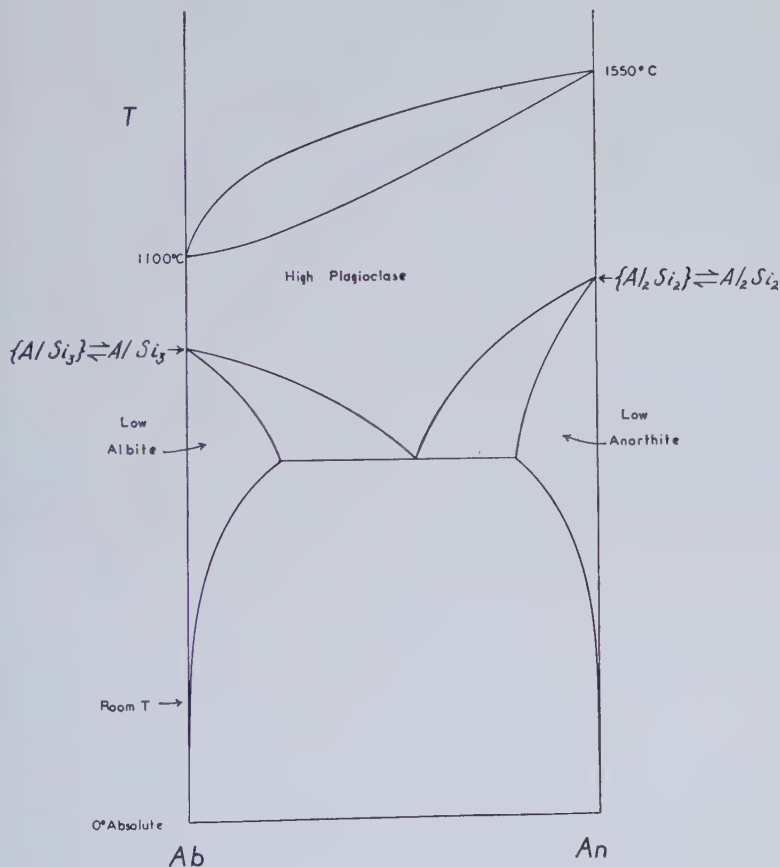


FIG. 4

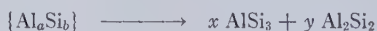
Chao and Taylor presented mere data, without attempting to explain what they had found. I do not believe that their findings in any way vitiate the early phase diagram work^{19,20} on the precipitation of albite-anorthite solid solutions crystals from high-temperature melts. In my opinion their findings merely give experimental proof for what is quite

¹⁹ Day, A. L., and Allen, E. T., The isomorphism and thermal properties of the feldspars: *Carnegie Inst. Pub.* **31** (1905).

²⁰ Bowen, N. L., Melting phenomena of the plagioclase feldspars: *Am. Jour. Sci.* (4), **35**, 577-599 (1913).

obvious from an order-disorder point of view, namely, that complete solid solutions are stable and to be expected at high temperatures, but they are most unnatural and unstable at low temperatures, where order is required. When the natural feldspars are found below their ordering temperature, one cannot expect them to be in the form of solid solution crystals. This view, though radical, follows directly from the general theory I proposed some fifteen years ago for such situations.¹¹

To give specific form to my view of the plagioclase relationships, Fig. 4 is presented. On this diagram nothing is quantitative except the well-known melting relations of the crystals. The other aspects of the diagram are arrived at by realizing that the $\{\text{AlSi}_3\}$ of albite and the $\{\text{Al}_2\text{Si}_2\}$ of anorthite certainly require ordering at lower temperatures. The purely geometrical conditions for ordering a pair of atom species in the ratio 1:3 are different than required for the ordering of a pair of atom species in the ratio 1:1. Albite must, therefore, order as a different phase from anorthite and at a different temperature than anorthite, probably at a lower temperature. Furthermore, at reduced temperatures, it is impossible for irrational amounts of Al and Si, such as called for in intermediate feldspars, to become ordered without the splitting of the crystal into two phases. Thus, ordering the disordered pair $\{\text{Al}_a\text{Si}_b\}$ requires unmixing. Since albite and anorthite are both capable of becoming ordered, their structures are available for this purpose, and one would expect the disordered pair of atoms to become ordered by establishing these two specific ordered crystal forms as follows:



Here, conservation of atoms requires

$$\begin{cases} a = x + 2y \\ b = 3x + 2y \\ a + b = 4 \end{cases}$$

This, of course, is merely a specific example of the theory which was discussed more abstractly under *Disorder and Unmixing*.

This theory postulates three plagioclase phases. Both albite and anorthite have a common high temperature, disordered form, but distinct low temperature, ordered forms. (The high temperature form may well be monoclinic, and both albite and pericline twinning may be concerned with the inversion.) It also requires that the stable low temperature state of the intermediate plagioclases is that of a mixture of end members, not solid solutions. If the intermediate plagioclase was formed above the ordering temperature, then the room temperature form of the stable mixture is an unmixed aggregate. If the plagioclase was deposited below the ordering temperature, then the form of the stable mixture is

that of an overgrowth or intergrowth of end members. All of this may be complicated by a second inversion concerned with the ordering of the alkali atoms. It should be noticed that conditions of deposition are not always conducive to the achievement of equilibrium. Slow deposition from nonviscous media favor equilibrium.

The plagioclase situation should be a warning not to accept solid solutions as necessarily stable at room temperatures. Chances are good that any solid solution mineral formed at the comparatively high temperatures ordinarily assumed for the formation of igneous and some metamorphic rocks is not a stable solid solution at the temperature of observation, because considerable more order is required at this low temperature. The presence of play of colors, such as so frequently seen in labradorite, or of schiller, or opalescence, may provide a clue that the crystal is possibly not, indeed, a solid solution.

I hope that in this sketchy account I have been able to convince you that it is important for a mineralogist to have a background of dynamic structural crystallography, and that such a background provides a rational frame for understanding and filing away his knowledge of the temperature relations of minerals.

MANSFIELDITE, A NEW ARSENATE, THE ALUMINUM ANALOGUE OF SCORODITE, AND THE MANSFIELDITE-SCORODITE SERIES*

VICTOR T. ALLEN AND JOSEPH J. FAHEY,
WITH X-RAY NOTES BY JOSEPH M. AXELROD,
U. S. Geological Survey, Washington, D. C.

ABSTRACT

The name mansfieldite is given to a new mineral having the formula $\text{Al}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$, the aluminum analogue of scorodite. It occurs at Hobart Butte, Lane County, Oregon, and together with intermediate members near the iron end of the mansfieldite-scorodite series, was formed by hydrothermal solutions. Mansfieldite occurs as white to pale gray, porous, cellular masses of spherulitic fibers. Chemical, optical, and x-ray data are recorded for mansfieldite, scorodite, and an aluminian scorodite. The specific gravity of mansfieldite is 3.03 and of scorodite 3.278. The indices of refraction of mansfieldite are: $\alpha=1.622$, $\beta=1.624$, and $\gamma=1.642$; of the aluminian scorodite: $\alpha=1.741$, $\beta=1.744$, and $\gamma=1.768$; and of scorodite: $\alpha=1.784$, $\beta=1.795$, and $\gamma=1.814$. Both 2V and the birefringence increase with increasing iron content.

INTRODUCTION

A hydrous aluminum arsenate recently discovered at Hobart Butte, about fourteen miles south of Cottage Grove, Lane County, Oregon, has proved to be a new mineral, the aluminum analogue of scorodite. This new mineral, $\text{Al}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$, is named mansfieldite in honor of the late Dr. George R. Mansfield, former Chief of the Section of Areal and Non-metalliferous Geology, U. S. Geological Survey. This discovery not only adds a new member to the small and rare group of natural aluminum arsenates¹ but also has enabled us to establish the variations in physical properties of intermediate members of the mansfieldite-scorodite series. The occurrence of mansfieldite also contributes to an understanding of the geologic history of an important high-alumina clay deposit, for the conditions of the origin of mansfieldite at Hobart Butte are clearly indicated.

The first specimen of this new hydrous aluminum arsenate was collected by the senior author on July 29, 1942, in the company of Robert L. Nichols, who was mapping the clay deposit as part of a joint program of the U. S. Geological Survey and the U. S. Federal Bureau of Mines on high-alumina clay. In January 1943, R. M. Denning² published a note on

* Published by permission of the Director, U. S. Geological Survey.

¹ Clarke, F. W., An aluminum arsenate from Utah: *Jour. Wash. Acad. Sci.*, **2**, 516-518 (1912).

² Denning, R. M., Aluminum-bearing scorodite from Hobart Butte, Oregon: *Am. Mineral.*, **28**, 55-57 (1943).

an aluminum-bearing scorodite from Hobart Butte, Oregon. In November 1943, excellent specimens of mansfieldite and of an intermediate member of the series labeled "representative specimens of rock types from Hobart Butte, Oregon," collected by R. L. Nichols, were received for petrographic study. Dr. Nichols has graciously placed these specimens at the disposal of the writers during this investigation.

The discovery of mansfieldite was first announced at a joint meeting of the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers in February 1944³ in one of six papers presented by members of the U. S. Geological Survey⁴ to honor Dr. Mansfield on the occasion of his retirement from the Survey.

GEOLOGIC OCCURRENCE

Hobart Butte, Lane County, Oregon, consists of altered pyroclastic rocks, chiefly of andesitic composition and water-laid sediments belonging to the Calapooya formation of probable Eocene age.⁵ Among the sediments are conglomerates⁶ containing white kaolinite pellets surrounded by a gray, brown, or reddish matrix of clay, organic matter, charcoal fragments, silicified wood, diatoms, and minor amounts of quartz and silicified volcanic fragments. In places conspicuous stratification is developed by the alignment of the long axes of the pellets in one direction and by streaks of organic material curving around them. The structure and composition of these sediments together with the somewhat plastic condition of the pellets which permitted them to be molded against grains of quartz, rock fragments, and other pellets, at the time of deposition, indicate that the kaolinitic pellet clay at Hobart Butte had the composition of kaolinite when it was deposited. The presence of kaolinite books in a leaf-bearing shale on the southwest side of Hobart Butte, about 200 feet below the summit is further evidence of a supply of kaolinitic clay in the area at the time of deposition of the Calapooya formation. Many features of the sediments at Hobart Butte suggest their derivation from an Eocene profile of weathering, which furnished not only white kaolinitic clay for pellets and books, but also reddish clay high in iron for the matrix surrounding the white pellets and the pumice fragments altered to kaolinite. The alteration of pumice fragments to

³ Allen, V. T., Sedimentary and volcanic processes in the formation of high-alumina clays: *Econ. Geol.*, **39**, 80, 85, 250 (1944); **41**, 124-138 (1946).

⁴ Smith, H. I., Report of Industrial Minerals Division, *Min. and Met.*, **25**, 217 (1944).

⁵ Wells, F. C., and Waters, A. C., Quicksilver deposits of southwestern Oregon: *U. S. Geol. Survey, Bull.* **850**, 26-35 (1934).

⁶ Allen, V. T., and Nichols, R. L., Clay-pellet conglomerates at Hobart Butte, Lane County, Oregon: *Jour. Sedimentary Petrology*, **15**, 25-33 (1945).

white kaolinite after they were surrounded by reddish or purplish clay could not have taken place without accompanying bleaching of the ferric iron of the matrix to reach the enclosed fragments or pellets. It therefore seems likely that some volcanic glass and breccia fragments were altered to kaolinite before they were embedded in the strongly colored clay matrix by stream deposition during the Eocene.

The rocks of Hobart Butte were invaded by hydrothermal solutions, probably in late Miocene time⁷ and realgar, stibnite, pyrite, arsenates, quartz, dickite, and other minerals were deposited. The hydrothermal solutions altered volcanic glass and lithic fragments to kaolinite which appears practically isotropic. Some of the pumice retained its original texture so well during the alteration that one receives the impression that the cloudy, nearly isotropic material is the original glass, but all the specimens isolated and examined have the indices of refraction and the x -ray pattern of kaolinite. In many specimens the development of kaolinite from glass and lithic fragments was accompanied by the crystallization of quartz so fine-grained that it escapes detection except in x -ray patterns. However, in a few specimens, quartz of microscopic size occurs as prismatic crystals having well-developed terminations. At the summit of Hobart Butte, the glass of welded tuffs is altered to an isotropic-appearing material giving the x -ray patterns of kaolinite and of quartz. Parts of the tuff showing relict pumice texture were hand-picked and analyzed for "available alumina," which is the alumina that can be extracted with 20 per cent sulfuric acid from a clay that has been calcined at a temperature of 700° C. The available alumina of the altered glass at Hobart Butte, determined by Margaret D. Foster in the Chemical Laboratory of the U. S. Geological Survey and based upon the weight of the sample dried at 130° C., is 27.4 per cent. This contrasts with the less than one per cent of available alumina in an unaltered vitric tuff from Camanche, California.

A white kaolin mineral accompanied by finely divided quartz fills cracks ranging from 1 to 8 mm. in width that cut across rock fragments in the lower part of the deposit at Hobart Butte. In thin sections, this mineral shows the mosaic intergrowth characteristic of the massive dickite from Chihuahua, Mexico, and Neurode, Silesia. However, all the specimens from Hobart Butte, including one in which small areas had an extinction angle of about 16°, gave the x -ray pattern of kaolinite. This suggests that the amount of dickite present is too small to be recorded

⁷ Wells, F. C., and Waters, A. C., *loc. cit.*, p. 25.

Callaghan, Eugene, and Buddington, A. F., Metalliferous mineral deposits of the Cascade Range in Oregon: *U. S. Geol. Survey, Bull.* 893, 21 (1938).

in the x-ray pattern of a mixture mainly kaolinite, and that the temperature of the hydrothermal solutions may have been sufficiently high at first to allow some dickite to crystallize but soon was lowered to a stage where kaolinite crystallized.⁸ The available alumina of a typical veinlet giving the x-ray patterns of kaolinite and of quartz was determined by Margaret D. Foster to be 26.7 per cent.

Siderite scales cover the surface of some kaolinite having a mosaic intergrowth and containing admixed quartz and also fill cracks in the clay. Siderite nodules, with or without a radial structure, fill openings in the pellet clay and the altered andesitic breccias. Some of the siderite nodules appear to be cut by stringers of realgar, and this arrangement suggests that some siderite was deposited by hydrothermal solutions after kaolinite and before realgar. Siderite and iron oxides are responsible for the high iron content of some of the Hobart Butte clays. Wells and Waters⁹ consider that the oxidation of siderite caused pronounced iron oxide ribs at Hobart Butte and at Black Butte about two miles away. Pyrite crystals of pyritohedral habit occur in the siderite and kaolinite veinlets. Marcasite has been reported¹⁰ in the Black Butte area, but definite proof is lacking that any of the iron sulfide at Hobart Butte is marcasite.

Tiny acicular crystals of stibnite occur in small amounts in some of the clay and locally comprise radiating groups of crystals 3 mm. in diameter. The greatest concentration of stibnite is along slickensides, where needles of microscopic size form aggregates a millimeter or so in thickness. The time relations of stibnite to the other sulfides and to the arsenates are unknown.

Realgar is the most conspicuous sulfide at Hobart Butte, where it is distributed along slickensides, in cracks, and in the matrix of the pellet clay. Some of the realgar conforms to the striated grooves of the slickensides and some of the realgar is itself slickensided. This suggests that the pellet clay was slickensided before the hydrothermal solutions brought in realgar, that the slickensides served as one type of opening for the invading solutions and that movement along slickensides was renewed during or after the deposition of realgar.

The arsenates of iron and aluminum occur as colloform crusts along open cavities in the clay. The time relations of the arsenates to the sulfides are unknown because at no place were they observed in contact.

⁸ Ewell, R. H., and Insley, H., Hydrothermal synthesis of kaolinite, dickite, beidellite, and nontronite: *Jour. Nat. Bur. Stand.*, **15**, Research paper R.P. 819, 173-186 (1935).

⁹ *Loc. cit.*, p. 34.

¹⁰ Wells, F. C., and Waters, A. C., *loc. cit.*, p. 25.

However, it is believed that they were deposited by hydrothermal solutions similar to those which have deposited scorodite at other localities.¹¹ The presence of realgar and stibnite in the same deposit is also suggestive of deposition by hot ascending waters related to volcanic processes.¹²

Some re-arrangement of kaolinite by hydrothermal solutions is indicated by (1) the occurrence of kaolinite in veinlets, and (2) the cavities formed by the removal of kaolinite and now partially filled with scorodite, mansfieldite, realgar, and siderite. Where hydrothermal solutions moved along the slickensides in the sedimentary clay now exposed in the Hobart Butte quarry, little new kaolinite was formed to increase the alumina content of the clay. Bleached zones from one to several centimeters wide were produced by the removal of some organic matter and iron. The alumina content of the bleached zone was increased only by an amount equal to that resulting from the removal of iron and organic matter and this amounted to less than one per cent in the specimens analyzed.

MANSFIELDITE AND ALUMINIAN SCORODITE AT HOBART BUTTE

Mansfieldite is white to pale gray, has a vitreous luster, a hardness of about 3.5, a spherulitic or axiolic structure, and occurs as porous, cellular masses ranging in length from a few centimeters to about 20 centimeters. Optically, mansfieldite is positive, has indices of refraction: $\alpha = 1.622$, $\beta = 1.624$, $\gamma = 1.642$, $2V$ (measured) very close to 30° , and dispersion $r > v$. In thin section, mansfieldite appears as clear bands with an aggregate structure or intergrown with kaolinite. Care was taken, in determining the optical properties listed in Table 2, to select only clear grains, because those intergrown with kaolinite gave low values for both refringence and birefringence. The presence of kaolinite and quartz with the mansfieldite complicated the interpretation of the analysis, which was made on the mixture of the three minerals.

In occurrence and appearance, the aluminian scorodite differs from mansfieldite in one respect only—the color is light green. At the Hobart Butte quarry, lumps of both minerals, large enough to be seen easily, are removed by hand during the mining of the clay and discarded. In hand specimen, the aluminian scorodite resembles some varieties of opal or

¹¹ Hague, J. D., Notes on the deposition of scorodite from arsenical waters in Yellowstone National Park: *Am. Jour. Sci.* (3), **34**, 171–175 (1887).

¹² Weed, W. H., and Pirsson, L. V., Occurrence of sulfur, orpiment and realgar in the Yellowstone National Park: *Am. Jour. Sci.* (3), **42**, 401–405 (1891).

Becker, G. F., Geology of the quicksilver deposits of the Pacific Slope: *U. S. Geol. Survey, Mon.* **13**, 349 (1888).

chalcedony. No individual or terminated crystals were observed. Optically, the mineral is positive, has indices of refraction: $\alpha=1.741$, $\beta=1.744$, $\gamma=1.768$, a measured 2V of approximately 40° , and dispersion $r > v$. In thin section, most of the aluminian scorodite appears as colloform crusts, with variable indices of refraction. In crushed samples examined in immersion oils with a petrographic microscope, some grains showed two or more zones of different indices. Such material was discarded as unsatisfactory for chemical analysis. The aluminian scorodite in Table 2 was composed mainly of one member and the optical properties recorded are believed to be those of the dominant member present.

At Hobart Butte no scorodite has been found thus far which represents the pure iron end member. In order to record additional chemical and optical data for the scorodite end of the series, a specimen that had been collected by W. F. Foshag at Durango, Mexico, was obtained from the U. S. National Museum. The indices of refraction are: $\alpha=1.784$, $\beta=1.795$, $\gamma=1.814$, 2V (measured) approximately 75° , and dispersion $r > v$. These data (Table 2) agree closely with those obtained by Foshag for analyzed scorodite from Gold Hill, Utah,¹³ and from Mapimi, Mexico.¹⁴

The lack of scorodite free from alumina, as well as the textural relations of the aluminian scorodites and mansfieldite to kaolinite, suggests that the hydrothermal solutions depositing the arsenates at Hobart Butte had assimilated alumina from the clay. Colloform crusts composed of various proportions of aluminum and iron arsenate as well as the nearly iron free mansfieldite were deposited locally by these solutions in an intimate intergrowth with kaolinite. The only uncontaminated mansfieldite forms thin bands adjoining zones of intergrown mansfieldite and kaolinite.

CHEMICAL COMPOSITION OF MANSFIELDITE

Petrographic and x-ray examinations showed that the mansfieldite was intimately associated and intergrown with quartz and kaolinite. This necessitated the application of a procedure that would correctly allocate the SiO_2 between the quartz and the kaolinite, and the Al_2O_3 and H_2O between the kaolinite and the mansfieldite. The complete analysis of the sample was made as follows:

¹³ Foshag, W. F., Berman, H., and Doggett, R. A., Scorodite from Gold Hill, Toole County, Utah: *Am. Mineral.*, **15**, 390-391 (1930).

¹⁴ Foshag, W. F., Carminite and associated minerals from Mapimi, Mexico: *Am. Mineral.*, **22**, 482 (1937).

TABLE 1. ANALYSIS OF MANSFIELDITE

Chemical Analysis of Sample Containing Mansfieldite, Kaolinite and Quartz		Calculated Mineral Composition			
	Per cent		Per cent		Per cent
SiO ₂	14.58	Quartz	3.25	SiO ₂	3.25
Al ₂ O ₃	25.78	Kaolinite	24.37	SiO ₂	11.33
Fe ₂ O ₃	.66			Al ₂ O ₃	9.63
TiO ₂	2.20			H ₂ O	3.41
As ₂ O ₅	39.12	Mansfieldite (Recalculated to 100 per cent in Table 2)	69.32	Al ₂ O ₃	16.15
Sb ₂ O ₅	.08			Fe ₂ O ₃	.61
P ₂ O ₅	.41			TiO ₂	.63
H ₂ O-110° C.	.35			As ₂ O ₅	39.12
H ₂ O+110° C.	15.73			Sb ₂ O ₅	.08
CuO	.16			P ₂ O ₅	.41
CaO	.02			H ₂ O	12.32
MgO	.02	Insoluble in H ₂ SO ₄	1.62	TiO ₂	1.57
Na ₂ O	.28			Fe ₂ O ₃	.05
K ₂ O	.03	Soluble in H ₂ SO ₄	.51	Na ₂ O	.28
Organic Matter	.38			K ₂ O	.03
Total	99.80			CuO	.16
Sp. Gr.	2.903			CaO	.02
				MgO	.02
		Organic Matter	.38		.38
		H ₂ O-110° C.	.35		.35
		Total	99.80		99.80

A half gram sample was treated in a small platinum dish with 15 ml. of H₂SO₄ (1:2) and heated on the steam bath overnight. The mansfieldite dissolved completely, the quartz and most of the kaolinite remained insoluble. The contents of the dish were washed into a 400 ml. Erlenmeyer flask, the dish was washed with 20 ml. of water, the washings and 200 ml. of concentrated HCl being added to the flask. Arsenic was precipitated by H₂S from the cold solution, the filtered precipitate was dissolved in NaOH and H₂O₂, reduced with SO₂ by the method of Kurtenacker and Furstenau,¹⁵ and finally titrated with standard iodine solution. Antimony was precipitated as the sulfide in the filtrate from the

¹⁵ Kurtenacker, A., and Furstenau, E., *Zeits. Anorg. Allgem. Chem.*, **212**, 289 (1933).

arsenic sulfide precipitation, after diluting with water to 900 ml. and allowing to stand over night before filtering. It was determined gravimetrically as Sb_2S_5 . No tin was present. In the filtrate Fe_2O_3 , P_2O_5 , TiO_2 , CaO , and MgO were determined and their percentages recorded in Table 1. Alumina was not determined on this sample because a small amount of the clay had been decomposed by the H_2SO_4 . Total SiO_2 , Fe_2O_3 , Al_2O_3 , P_2O_5 , and TiO_2 were determined on a separate sample. The difference between the total Fe_2O_3 and the Fe_2O_3 soluble in H_2SO_4 gave 0.05 per cent Fe_2O_3 insoluble in H_2SO_4 . Likewise 1.57 per cent TiO_2 was found to be insoluble in H_2SO_4 . All of the P_2O_5 , CaO , MgO , and the alkalis present in the sample were soluble in H_2SO_4 . Water was determined by the Penfield glass tube method and 0.16 per cent CuO soluble in H_2SO_4 was found in a separate sample.

It was evident that if the percentage of quartz could be measured and deducted from the percentage of total SiO_2 , the remaining percentage of SiO_2 could be allotted to kaolinite and from that figure the percentage of the kaolinite in the sample could be computed. The Al_2O_3 of the kaolinite could then be deducted from the total Al_2O_3 , leaving the percentage of Al_2O_3 present in the sample as aluminum arsenate. Similarly, the total H_2O would be divided between the kaolinite and the mansfieldite.

In order to make these computations, the percentage of quartz present was determined by treating a gram sample in a small platinum dish with 30 ml. H_2SO_4 (1:2), heating on the steam bath overnight, then diluting with water and carefully decanting after the insoluble portion had settled. Five ml. HF (1:4) were then added to the residue and stirred at room temperature for one minute, diluted with water, and after allowing to settle, carefully decanted. The residue was transferred to a larger platinum dish, 50 ml. of a 10 per cent Na_2CO_3 solution were added, and heated to boiling for ten minutes. It was then diluted with water, allowed to settle, and carefully decanted. After treating the residue with 15 ml. HCl (1:2) and heating on the steam bath for 15 minutes, the quartz was filtered, ignited, and weighed. Examination with the petrographic microscope showed the quartz to have only a negligible amount of impurities. With this figure for quartz and the complete analysis of the sample, the percentages of quartz, kaolinite, and mansfieldite were readily computed and are recorded in Table 1. The mansfieldite analysis is recalculated to 100 per cent in Table 2.

The specific gravity of mansfieldite was computed at 3.03 by determining the specific gravity of the analyzed sample (Table 1) and applying the proper corrections for the percentages of kaolinite and quartz present.

The analyses of the sample of scorodite and of the intermediate mem-

ber of the series, Table 2, differ from that of the sample of mansfieldite in that the samples are almost free from any extraneous insoluble matter.

THE MANSFIELDITE-SCORODITE SERIES

It is well established that scorodite crystallizes in the orthorhombic system, and on the basis of similar optical and x-ray properties, mansfieldite is also probably orthorhombic. The molecular ratio of the intermediate member, Table 2, agrees very closely with the 1:1:4 ratio required by the formula of scorodite and its aluminum analogue, mansfieldite. Two straight-line curves are drawn (Fig. 1), representing the variation in the alpha and gamma indices of the members of the mans-

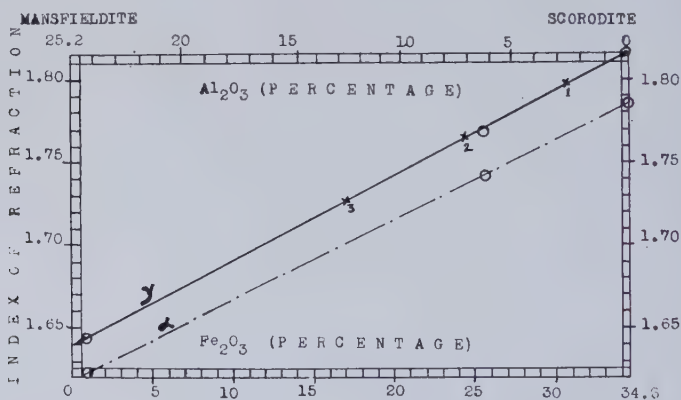


FIG. 1. Curve showing relation of indices of refraction of mansfieldite-scorodite series to percentage of alumina and ferric oxide present. Points 1 and 2 are after Larsen, 3 is after Denning, and 0 is aluminian scorodite recorded in Table 2.

fieldite-scorodite series. The lines terminate on the left with the alpha and gamma indices of mansfieldite and on the right with those of scorodite. The lower abscissa is divided to represent the percentages of ferric oxide in the series, ranging from 0 in pure mansfieldite to 34.6 in pure scorodite. The upper abscissa is divided to represent the percentages of alumina, ranging from 0 in pure scorodite to 25.2 in pure mansfieldite. The gamma index of 1.768 for the aluminian scorodite listed in Table 2, plotted on the curve, gives percentages of 25.7 and 6.2, respectively, of Fe_2O_3 and Al_2O_3 . These figures closely approximate the values found in the chemical analysis.

Two specimens,¹⁶ listed by Larsen as scorodite (1 and 2 of Fig. 1) appear to be intermediate members of this series: (1) an unanalyzed sam-

¹⁶ Larsen, E. S., Microscopic determination of nonopaque minerals, *U. S. Geol. Surv., Bull.* 679, 132 (1921).

ple from Nassau, Germany, with $\gamma=1.797$ would have, according to the curve (Fig. 1), 30.7 per cent Fe_2O_3 and 2.8 per cent Al_2O_3 ; (2), with $\gamma=1.765$ would have 24.5 per cent Fe_2O_3 and 7.2 per cent Al_2O_3 . (2) an analyzed sample from Black Pine, Idaho, contains, according to the analysis, 4.80 per cent P_2O_5 and no Al_2O_3 . Hence it seems that iron

TABLE 2. MANSFIELDITE-SCORODITE SERIES

	Mansfieldite (Recalculated) Hobart Butte $\text{Al}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$		Aluminian Scorodite Hobart Butte $(\text{Fe}, \text{Al})_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$		Scorodite Durango, Mexico $\text{Fe}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$	
	Per cent	Molecular Ratio	Per cent	Molecular Ratio	Per cent	Molecular Ratio
Al_2O_3	23.30	.99	5.76	1.00	None	1.01
TiO_2	.91		.06		.02	
Fe_2O_3	.88		25.72		34.79	
As_2O_5	56.43	1.01	48.88	1.03	49.52	1.00
Sb_2O_5	.12		.74		.06	
P_2O_5	.59		1.72		None	
$\text{H}_2\text{O}+$	17.77	3.99	15.86	3.98	15.44	3.98
$\text{H}_2\text{O}-$	—		1.18		None	
SiO_2	—		.20		.30	
Total	100.00		100.12		100.13	
Sp. Gr.	3.031		3.135		3.278	
Alpha	1.622		1.741		1.784	
Beta	1.624		1.744		1.795	
Gamma	1.642		1.768		1.814	
B.	.020		.027		.030	
2V	$30^\circ \pm$		$40^\circ \pm$		$75^\circ \pm$	
Disp.	$r > v$		$r > v$		$r > v$	

aluminum arsenates in which As_2O_5 is in large part replaced by P_2O_5 are not amenable to measurement by this chart (Fig. 1). The specimen of aluminian scorodite from Hobart Butte (3 on Fig. 1) which was measured by Denning¹⁷ with $\gamma=1.728$ would contain, according to this curve, 17.0 per cent Fe_2O_3 and 12.7 per cent Al_2O_3 . Measurements

¹⁷ *Loc. cit.*, p. 55 (1943).

TABLE 3. POWDER DIFFRACTION PATTERNS—UNFILTERED IRON RADIATIONS

Mansfieldite		Aluminian Scorodite		Scorodite	
<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
6.00	mw	6.10	m	6.16	m
5.45	vvs	5.52	vs	5.56	vvs
4.84	m	4.89b	ms	4.95	ms
4.36	vvs	4.41	vvs	4.44	vvs
3.97	ms	4.02	m	4.06	m
3.71	mw	3.75	m	3.78	m
3.41	mw	3.47	mw	3.50	m
3.32Q	mw	3.35	mw	3.36	m
3.29	mw	3.28	w		
3.09	vs	3.14	s	3.16	vvs
2.98	s	3.03	ms	3.05	s
2.92	m	2.97	m	2.98	ms
2.77	w	2.83	w	2.84	mw
2.68	m	2.74	mw	2.75	mw
2.62	m	2.67	mw	2.67	m
2.52	s	2.57	ms	2.58	vs
2.44	m	2.48	m	2.50	ms
2.25	w	2.30	w	2.31	mw
2.18	mw	2.22	vw		
2.08	w	2.17	w	2.18	mw
		2.12	vw	2.13	mw
		2.09	vw	2.11	mw
2.00	w	2.03	w	2.04	mw
1.959	mw	1.991	mw	2.00	m
1.779	mw	1.824	w	1.836	mw
1.753	mw	1.784	w	1.797	mw
1.709	mw	1.748	w	1.753	mw
1.627	ms	1.653	m	1.664	ms
		1.626	w	1.645	mw
1.543	mw			1.583	mw
1.480	m	1.505	w	1.513	mw
1.401	mw	1.468	w	1.473	m
		1.434	w		
1.361	mw	1.397	w	1.401	mw
1.276	mw				
1.263	mw	1.295	w	1.280	mw
1.215	m	1.226	vw	1.230	mw
1.178	mw			1.207	mw
1.169	mw	1.193	w	1.197	mw
1.084	mw	1.106	w	1.110	mw
				1.054	mw
				1.018	mw
.996	m			1.006	m
				.998b	mw

b=broad.

on several specimens indicate that some colloform crusts from Hobart Butte have indices of refraction intermediate between the values reported by Denning and those of mansfieldite, but the material is so interbanded that it is unsatisfactory for chemical analysis.

X-RAY ANALYSIS

X-ray photographs were made of the three samples analyzed, namely mansfieldite, aluminian scorodite, and scorodite. Debye-Scherrer cameras of 57.3 mm. radius and unfiltered iron radiation were used; intensities of the lines were estimated visually. Because the scorodite sample was better crystallized than the two aluminous minerals, it gave a sharper diffraction pattern, but the patterns are all strikingly similar and undoubtedly represent isostructural minerals. The similarity is significant also, in that the progressively smaller increases in interplanar spacings with increasing iron content may be used, in the absence of other composition variations, to estimate the scorodite content to a precision of about ten per cent.

The measurements on the stronger lines of each pattern are given in Table 3. The mansfieldite contains kaolinite and quartz, and one line partly due to quartz is marked with a *Q*. The unit cell and space group of scorodite have been published by Kokkoros¹⁸ and McConnell.¹⁹

ISOMORPHISM AMONG PHOSPHATES AND ARSENATES

It has been shown in this paper that mansfieldite and scorodite are end members of an isomorphic series. The literature contains many analyses of samples intermediate between variscite and strengite, the phosphate analogues of mansfieldite and scorodite. These four orthorhombic minerals may be placed at the four corners of a tetrahedron. In view of the fact that isomorphism has been found only between end members having the same acid radical, the question as to whether or not isomorphism can exist between end members with different anions presents itself. Is isomorphism possible between mansfieldite, and variscite or strengite, or between scorodite, and variscite or strengite? The aluminian scorodite, Table 2, containing 1.72 per cent P_2O_5 and the scorodite from Black Pine, Idaho (number 2, Fig. 1) containing 4.80 per cent P_2O_5 seem to indicate that such isomorphism may exist.

¹⁸ Kokkoros, Peter, Vergleichende Röntgenographische Untersuchung von Arsenaten und Selenaten: *Praktika Acad. Athens*, **13**, 337-344 (1938); *Min. Abs.*, **8**, 140 (1941).

¹⁹ McConnell, Duncan, Clinobarrandite and the isodimorphous series, variscite-meta-variscite: *Am. Mineral.*, **25**, 719-725 (1940).

ACKNOWLEDGMENTS

The authors are grateful for the helpful suggestions of their colleagues and in particular to Mr. W. G. Schlecht for his help in outlining the method used in the determination of As_2O_5 and to Mr. K. J. Murata, who spectrographed the samples. Appreciation is expressed, also, to Dr. Clarence S. Ross, Dr. Waldemar T. Schaller, Dr. Earl Ingerson and Dr. Michael Fleischer for their aid, suggestions, and critical reading of the manuscript.

SECOND OCCURRENCE OF BRAZILIANITE

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ABSTRACT

Brazilianite occurs in the Palermo pegmatite, North Groton, Grafton County, New Hampshire. It differs in crystal habit from that of the crystals from Brazil. Chemical analysis confirms the formula $\text{NaAl}_3(\text{PO}_4)_2(\text{OH})_4$. X-ray data and the physical properties agree in general with those given in the original description. The optical properties of the mineral from Brazil have been redetermined more accurately.

INTRODUCTION

A second locality for brazilianite, at the Palermo mine, North Groton, New Hampshire, has been found. The mineral was originally described in 1945 by Pough and Henderson from a pegmatite in the Conselheira Pena district, Minas Geraes, Brazil, and supplementary notes were later published by others (see appended bibliography).

Brazilianite was recognized and collected by the writers during a visit to the Palermo mine in July, 1947, and a considerable amount of additional material was obtained in later visits. The mineral occurs rather abundantly, although only locally, associated with whitlockite, apatite, and quartz in a granite pegmatite presently being worked for mica, feldspar, and beryl. The writers wish to express their appreciation to Mr. H. A. Ashley, operator of the mine, for his cordial aid in collecting material at the locality.

OCCURRENCE AND PARAGENESIS

The Palermo pegmatite mine (Palermo Number One), first opened about 1863, has been one of the foremost producers of mica in New England and is currently being worked for feldspar and beryl. The present workings are in the form of an irregular open pit in the exposed central part of the pegmatite and they overlie, without connection, extensive underground workings.

The Palermo Number One pegmatite has a roughly oval-shaped outcrop 160 by 220 feet, on the top and south side of a low knob. It is a lens-shaped dike which strikes about N. 30° E., dips about 50° southeast, and plunges about 45° northeast.

* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 294.

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The pegmatite is well-zoned internally, as are many of the other pegmatites in the immediate vicinity. The zoning was studied in detail by members of the U. S. Geological Survey¹ during the pegmatite investigations in New England from 1942 to 1945. For the present description, the zones may be divided into three groups:

(1) The outer zones of fine- to medium-grained texture contain quartz, muscovite, biotite, plagioclase (oligoclase to albite) and black tourmaline.

(2) The intermediate zone, coarse-grained, contains quartz, muscovite, biotite, albite, perthite, beryl, tourmaline, lazulite, other phosphates, and small amounts of sulfide minerals. The lower part of this zone has been worked for sheet-mica, and the upper part for feldspar and beryl. The beryl occurs in crystals up to eight feet long.

(3) The quartz core, at the center of the pegmatite, contains several other minerals, especially at the edge. Single crystals of triphylite range up to fourteen feet or more in length, affording cleavage blocks several feet square. Large perthite crystals are found here; bronze scrap mica and blue-green beryl are present in smaller amounts. The brazilianite that was found in place occurred in cavities essentially at the contact of the intermediate zones and the quartz core.

Locally, the pegmatite was traversed by late-stage, relatively low temperature hydrothermal solutions which preferentially attacked the triphylite with the formation of ludlamite, messelite (?), siderite, triploidite, apatite, and minor sulfides. The apatite in part, whitlockite, siderite, quartz, and minor quantities of an blygonite and eosphorite-childrenite occur as drusy crystals in small solution cavities in the altered triphylite. Albite was not formed in any significant amount by the solutions and albitization is generally absent in the part of the pegmatite exposed in the surface workings. Near the surface, the triphylite crystals, normally greenish- or bluish gray in color, are more or less oxidized to a soft brownish-black mass composed essentially of iron and manganese oxides, heterosite, secondary iron phosphates including dufrenite, and several unidentified minerals.

The brazilianite appears to belong to the above-mentioned hydrothermal period of formation; it has been found in the vicinity of, but not actually in, the altered triphylite crystals. It occurs as drusy crystals associated with small quartz crystals, tiny white hexagonal prisms of apatite and whitlockite, and in small anastomosing cavities in coarsely granular aggregates of feldspar and quartz. The sequence of formation was quartz-brazilianite-apatite-whitlockite-quartz. In part, the brazilianite occurs

¹ Pegmatite investigations in New England, 1942-1945, by E. N. Cameron, D. M. Larrabee, A. H. McNair, J. J. Page, V. E. Shainin, and G. W. Stewart, U. S. Geological Survey. (Report in preparation.)

as ill-formed crystals completely embedded in the granular wall rock of the cavities. This type of occurrence suggests that the brazilianite may be a relatively early deposit from the hydrothermal solutions or may represent a deposit from such solutions when not modified by reaction with the triphylite. At the outcrop, the granular brazilianite-matrix is rendered friable by weathering. Hundreds of brazilianite crystals were obtained from this material by separating them in the laboratory from the associated minerals by the use of heavy liquids.

CRYSTALLOGRAPHY

The brazilianite crystals from the Palermo mine, N. H., differ in habit from the crystals from Brazil principally in the near suppression of the

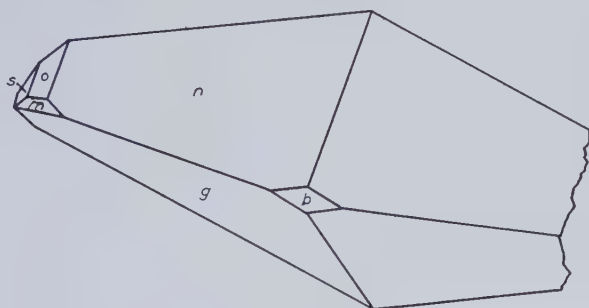


FIG. 1. Brazilianite from the Palermo mine. Drawn with the b -axis in front.

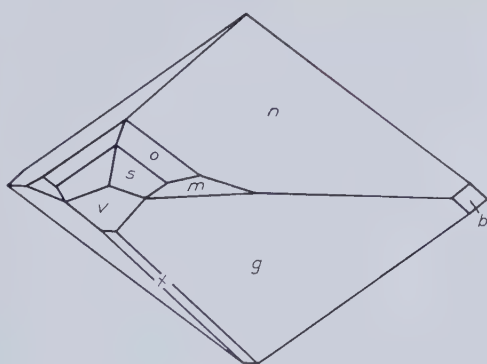


FIG. 2. Conventional projection of the crystal shown in Fig. 1.

prism zone and in the relatively large development of $n\{011\}$ and $g\{\bar{1}11\}$. This gives the crystals an elongate, four-sided appearance as shown in Fig. 1, in which the b -axis is drawn in front. In the conventional projection, Figure 2, the crystals appear rather foreshortened. The other forms

observed were $a\{100\}$, $o\{111\}$, $s\{211\}$, $q\{\bar{1}21\}$, $v\{\bar{3}01\}$, $x\{\bar{1}01\}$ and $b\{010\}$, none of which are new to the species. On 50 or so crystals examined under a binocular, all of the faces except $q\{\bar{1}21\}$ and $a\{100\}$ were present, although in varying and usually unequal development. The forms q and a were noted on only a few crystals and are not shown in the drawings. The crystals are attached to the matrix by one end of the $[100]$ axis, a feature also shown frequently by the Brazilian crystals.

Several crystals were measured on the two-circle goniometer. The quality of the reflections obtained was not very good, due to curvature and growth hillocks on the faces, especially $n\{011\}$ and $g\{\bar{1}11\}$. The best reflections are given by the modifying faces o , s , n , and v . The negative orthodome $x\{\bar{1}01\}$ ordinarily is present only as line-faces and does not afford readily distinguishable signals. In Table 1 the angles obtained from the averaged measurements of the best crystals are given in comparison

TABLE 1. ANGLE TABLE FOR BRAZILIANITE FROM PALERMO MINE,
NEW HAMPSHIRE

Monoclinic, prismatic $-2/m$
 $a:b:c=1.1056:1:0.6992$; $\beta=97^{\circ}22'$

Forms	Measured angles (Palermo)		Angles (Brazil) of Pough and Henderson	
	ϕ	ρ	ϕ	ρ
$a\ 100$	90°00'	90°00'	90°00'	90°00'
$b\ 010$	0 00	90 00	0 00	90 00
$m\ 110$	42 15	90 00	42 22	90 00
$n\ 011$	10 40	35 24	10 29	35 25
$x\ \bar{1}01$	-90 00	27 2	-90 00	26 57
$v\ \bar{3}01$	-90 00	60 47	-90 00	60 44
$o\ 111$	47 36	46 7	47 39	46 4
$g\ \bar{1}11$	-38 49	41 61	-36 2	40 51
$s\ 211$	63 11	57 31	63 33	57 30
$q\ \bar{1}21$	-19 58	56 00	-19 59	56 06

with the angles cited by Pough and Henderson.² Their choice of orientation and unit, it may be noted, is in 'agreement with the x-ray cell obtained independently by the Weissenberg method by Hurlbut and Weichel (5) and by the Laue and rotation method by Franco and Loewenstein (6). Hurlbut and Weichel give $a_0=11.19$, $b_0=10.08$, $c_0=7.06$, with $a_0:b_0:c_0=1.110:1:0.700$, and the space group $P2_1/n$.

² The original angle table of these authors contains numerous minor errors of computation and the values here given are recalculated from their elements.

The x-ray powder diffraction spacing data for the brazilianite from New Hampshire are given in Table 2. The patterns of the Palermo and Brazilian material correspond exactly.

TABLE 2. X-RAY POWDER SPACING DATA FOR BRAZILIANITE FROM PALERMO MINE, NEW HAMPSHIRE

Copper radiation, nickel filter

<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>
3	5.84	1	2.34	2	1.58
10	5.04	1	2.30	1	1.56
1	4.62	1	2.23	3	1.52
1	4.21	2	2.17	2	1.50
4	3.77	1	2.11	5	1.44
1	3.48	4	2.05	1	1.42
3	3.30	3	2.01	1	1.39
2	3.16	4	1.98	3	1.31
8	2.98	3	1.93	3	1.30
7	2.87	2	1.85	1	1.27
1	2.80	1	1.82	2	1.26
8	2.73	3	1.75	2	1.24
8	2.68	2	1.72	1	1.22
3	2.61	1	1.66	1	1.18
3	2.47	2	1.64	3	1.15
2	2.41	1	1.62		

PHYSICAL AND OPTICAL PROPERTIES

The properties of the mineral from the two localities are practically identical. The (010) cleavage is good in quality but not easily developed, and broken fragments commonly show many conchoidal fracture surfaces. The hardness is $5\frac{1}{2}$. The specific gravity of the Palermo crystals, determined on the microbalance, is $2.985 \pm .005$. A redetermination of the gravity of the Brazilian material gave $2.980 \pm .005$, which is somewhat higher than the two earlier reported determinations, 2.94 (1) and 2.976 (5). The color is pale yellow to chartreuse yellow, somewhat paler and less green than the Brazilian material in pieces of equal size. The crystals are transparent and have a vitreous luster. They range in size to as much as one inch measured along [100]. Most individuals are smaller, one-fourth inch or so on the average along [100].

The indices of refraction and optical orientation of the Palermo crystals as measured by the writers are given in Table 3. The data for the Brazilian material, given for comparison, are redeterminations with sodium light by M. L. Lindberg, and are closely confirmed by values obtained in white light by J. J. Glass and W. T. Pecora of the U. S. Geo-

logical Survey.³ The indices of refraction of brazilianite from Brazil originally given by Pough and Henderson were low by about 0.003. Optical data for the Brazilian crystals in agreement with those reported here⁴ were determined by Hurlbut and Weichel (5), but through inad-

TABLE 3. OPTICAL DATA FOR BRAZILIANITE

Orientation	n_{Na} (Palermo)	n_{Na} (Brazil)
$X \wedge c = -20^\circ$	$1.602 \pm .001$	$1.602 \pm .001$
$Y = b$	$1.609 \pm .001$	$1.609 \pm .001$
Z	$1.623 \pm .001$	$1.621 \pm .001$
$2V$ (calc.)	71°	75°
Sign	+	+
Dispersion	$r < v$, faint	$r < v$, faint

vertence, the original slightly lower values of Pough and Henderson were printed instead of their new data; the optical orientation given by Hurlbut and Weichel, $X = b$ and $Y \wedge c = 15^\circ$, is incorrect.

CHEMISTRY

A chemical analysis of the Palermo material made by M. L. Lindberg in the laboratory of the U. S. Geological Survey conforms closely to the

TABLE 4. CHEMICAL ANALYSES OF BRAZILIANITE

	1	2	3	•
Na_2O	8.56	8.29	8.42	
K_2O	—	0.20	0.37	
Al_2O_3	42.25	42.85	43.82	
Fe_2O_3	—	0.03	—	
TiO_2	—	0.05	—	
P_2O_5	39.23	38.79	37.97	
H_2O	9.96	$\begin{Bmatrix} +9.91 \\ -0.04 \end{Bmatrix}$	9.65	
Total	100.00	100.16	100.23	

1. Theoretical requirements for $NaAl_3(PO_4)_2(OH)_4$.
2. Palermo mine, North Groton, New Hampshire. M. L. Lindberg, analyst. Includes MnO trace; F none; Li_2O none. Ratios $Na_2O + K_2O : R_2O_3 : P_2O_5 : H_2O = .982 : 3.046 : 1.976 : 3.995$. Analysis on Harvard spec. no. 98124.
3. Conselheira Pena district, Minas Geraes, Brazil. E. P. Henderson, analyst. Includes Cl trace; F none. Analysis on U. S. National Museum spec. no. 105048.

³ Measured on the original analyzed sample, U. S. National Museum No. 105048.

⁴ C. S. Hurlbut, Jr., private communication, August 1947.

formula, $\text{NaAl}_3(\text{PO}_4)_2(\text{OH})_4$, established by the original analysis of Henderson (Table 4). The mineral is not attacked by oxalic, hydrochloric, nitric, or cold sulfuric acid, but is slowly decomposed by hydrofluoric and by hot sulfuric acid. The sodium carbonate fusion of the Palermo mineral is pinkish violet.

Spectrographic examination of brazilianite from both localities by H. C. Harrison⁵ shows traces of the following elements:

Palermo: $\text{Ca} > \text{Si}$, Cu , $\text{Be} > \text{Fe}$, Mg , Mn , Ti , V , Ba , Sr , $\text{Pb} > \text{Cr}$, B .

Brazil: $\text{Ca} > \text{Si}$, Cu , $\text{Pb} > \text{Fe}$, Mg , Mn , Ti , V , Sn , Zr , $\text{Ba} > \text{Cr}$, B , Ag , $\text{Be} > \text{Li}$.

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⁵ Department of Mineralogy and Petrography, Harvard University, Private communication, August 1947.

ZIRCONIUM FROM THE REGION OF POÇOS DE CALDAS

R. R. FRANCO AND W. LOEWENSTEIN*

ABSTRACT

Zircon occurs as single crystals, in crystal groups, and in botryoidal intergrowths with fibrous, radial zirconium oxide in the region of Poços de Caldas, Minas Gerais, Brazil. The forms noted are: $p\{111\}$, $a\{100\}$, $m\{110\}$, and $x\{311\}$. The amorphous zirconium oxide is believed to have been formed by precipitation from hot, ascending solutions that obtained their zirconium through the destruction of primary zirconium silicates (chiefly rosenbuschite, astrophyllite, and eudialyte). Much of the zircon appears to be later than the zirconium oxide and is believed to have resulted from the interaction of silica-bearing solutions with the oxide.

INTRODUCTION

This study is based on materials personally collected at Cascata, São Paulo and Poços de Caldas, Pocinhos do Rio Verde, in Minas Gerais, and in neighboring regions, and also on specimens in the Department



FIG. 1. Index map of Brazil, showing location of the Poços de Caldas region.

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of Mineralogy and Petrography of the University of São Paulo, Brazil. Additional study material was kindly donated by colleagues. Figure 1 shows the area in which the deposits occur. The specimens were obtained almost entirely from the following localities in the mineralized area: Córrego do Quartel, Serrote, Quirinos and Triângulo (Cascata); Campinas, Pouso Alegre, Campo do Alemão (Taquari), Coqueiro and Retiro dos Coqueiros, all in the region of Pocinhos do Rio Verde and Parreiras.

Our chief concern has been to study the principal forms of zircon and zirconium oxide and the general aspect of their complex occurrence. Special attention was given to chemical analyses. The discussion of the origin is based on the mineral relationships and the geology. It is not yet possible to draw conclusions as to the true chemical nature and structure of some of the minerals in the veins. The identification of these minerals will depend on x -ray studies now in progress in our department, for there is no chemical means for their determination.

PREVIOUS WORK

Because of the varied and important rôle played by these deposits of zirconium oxide and silicate, the Poços de Caldas region has been extensively and intensively studied both by foreign and Brazilian geologists. Worthy of attention are the works of Derby (5), Machado (15), Coburg (18), Hussak and Reitingner (14), Silva (19), Guimarães (10), Barbosa (1, 2) and Teixeira (20).

In Derby's work (5) no particular attention was paid to the problem of the zirconium; his interest was especially in the rocks that occur in the highland of Poços de Caldas, but he made a passing reference to large crystals of zircon from the region of Parreiras, and intimated that a zircon syenite or a variety of zircon foyaite might be the source rock of the zirconium minerals. He pointed out, however, that zircon had not been noted in any of the foyaite found in Brazil up to that time.

Machado (15), in describing the rocks of the region, noted the presence of the complex zirconiferous silicates—lâvenite and eucolite or eudialyte without mentioning zircon as one of the rock constituents.

Coburg (18) studied the crystallography and described some forms of zircon: $p\{111\}$, $m\{110\}$ and $a\{100\}$, which he encountered on scattered crystals in the sands of the River Verdinho. He called attention to the similar relations which exist between the zirconiferous deposits of the Poços de Caldas region and those of Norway, where augite nepheline syenites also occur.

Hussak (13) reported the discovery of the source rock of zircon when, while examining a specimen of decomposed augite syenite, he found hundreds of zircon crystals. He described, in addition to the idiomorphic

crystals of zircon, honeycombs of dark gray, black, and reddish-brown material. The chemical analysis of these honeycombs showed a high content of zirconium oxide (97 per cent). He suggested that the honeycombs might be a secondary decomposition product of zircon, which would be the most likely primary mineral of zirconium. Zircon would be transformed by a loss of SiO_2 into the oxide of zirconium encountered in the "combs."

Hussak and Reitingger (14), who studied in a detailed manner a large number of "combs," came to the conclusion that the percentage of SiO_2 varies within wide limits. This discovery suggested the hypothesis that the zirconium oxide "combs" might have originated from zircon. They showed that the percentage of silica varied between 2 and 15.5 per cent. They described the "combs" as being of fibrous-radial structure, which, when broken, fell into polyhedral pieces with smooth surfaces and poorly developed faces. They concluded, moreover, that the fibrous material, which contained more than 97 per cent ZrO_2 , had nothing to do with the baddeleyite described by Hussak in jacupiranguite from the region of Jacupiranga, São Paulo, Brazil.

Silva (19) states that the zirconium ore must have originated from a magmatic concentration of zirconium silicate in the nepheline rocks of the region. Later, through metasomatism the complex oxides of the ore, called "caldasite," must have been formed.

Djalma Guimarães (10), suggests a hydrothermal process at high temperatures and in an oxidizing medium as being responsible for the botryoidal masses of ore which occur in the region. He believes the "caldasite" was formed by hydrothermal metamorphism which brought about metasomatic replacement in the nepheline rocks.

Barbosa (1, 2) called attention to the presence of ore veins in the highly decomposed nepheline rocks. He concluded that all the zirconium comes from the alteration of these rocks—phonolites and foyaites. He, like Machado previously, pointed out the presence of zirconiferous silicates in the nepheline rocks and said that the zirconium ore must have begun to form soon after the extrusion of the last sheet of phonolitic lavas, which were rich in acid and alkaline solutions. As a result of several analyses, he thought that the zirconium oxide and the zircon were formed at the same time, and that both were of primary origin.

Teixeira (20), in referring to the occurrence of zirconium minerals, considered them as unique in their characteristics. In dealing with their genesis, he classified the deposits as of hydrothermal origin. The nepheline rocks of the region must have been attacked by alkaline solutions, after the eruptive period, with resultant solution of the zirconium of the zir-

coniferous silicates (eudialyte, rosenbuschite, l  venite) and later deposition of zirconium oxide in fractures.

MINERALOGY

Zircon

The zircon crystals occur as idiomorphs of various sizes—from microscopic up to individuals 4.5 cm. in width. In addition to irregular crystal groups, and less common parallel ones, isolated crystals are also encountered. In reflected light they are dark brown, reddish brown, green, greenish, greenish brown, or light green, and usually of adamantine brilliancy. Bi-colored individuals also occur. On the cleavage faces of polished crys-

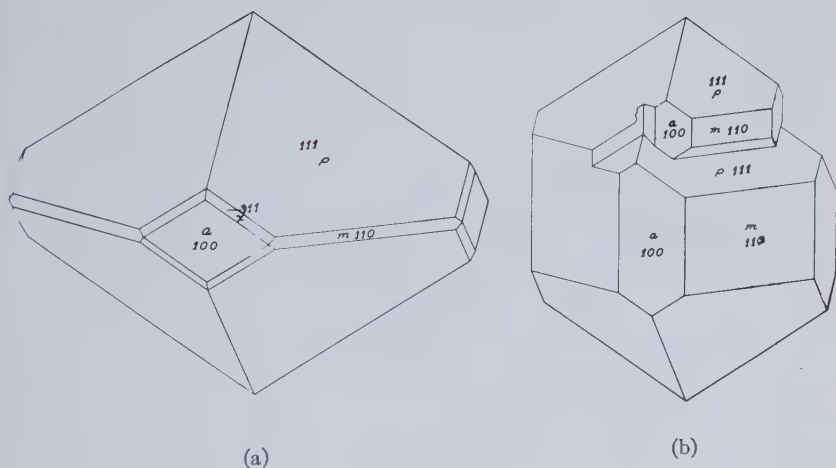


FIG. 2. (a) Zircon crystal of typical habit, showing most complex development.
(b) Parallel growth of two zircon crystals of typical habit.

tals color zones of varying widths are accentuated. On these faces the crystals show various iridescent colors. In transmitted light they are strongly colored. Internally they are fractured and full of cavities. The commonest habit is pyramidal. Such crystals may be simple, with $p\{111\}$, or with $p\{111\}$ and $a\{100\}$, which are sometimes equally developed so that the crystal resembles a dodecahedron. Other combinations include: $p\{111\}$ and $a\{100\}$ with predominant development of $p\{111\}$; $p\{111\}$, $m\{110\}$ and $a\{100\}$, the most common combination; $p\{111\}$, $m\{110\}$, $a\{100\}$ and $x\{311\}$, less common (Fig. 2a). The crystals of pseudododecahedral habit are found in the Campo do Alem  o (or Taquari) deposit. They are green and occur in veins of varying width, together with masses of microcrystalline zircon.

The largest crystal that we have had the opportunity to study belongs to the Mineralogy Museum of the Polytechnical School of Rio de Janeiro, Brazil. It measures 4.5 cm. in width, and is marked by numerous, irregularly distributed, triangular etch figures. The faces are also minutely striated. Figure 2b shows an unusual intergrowth of two individuals of the same orientation. This specimen measures 1.9 cm. along the direction of the c -axis.

The green crystals found in geodes and veins are generally the most translucent, and their surfaces are smooth and brilliant. No matter what the color of the crystals may be, they fluoresce an intense yellow. Optically the crystals from the Poços de Caldas area are either normally uniaxial or biaxial. Strongly colored sections show pleochroism.

"Combs" and fibrous-radial material

The "combs" resemble mammillary or botryoidal masses of limonite, hematite, rutile and manganese oxide. They have a fibrous or sub-fibrous structure, but massive or concretionary aggregations with an earthy texture are not rare. The hardness varies considerably.

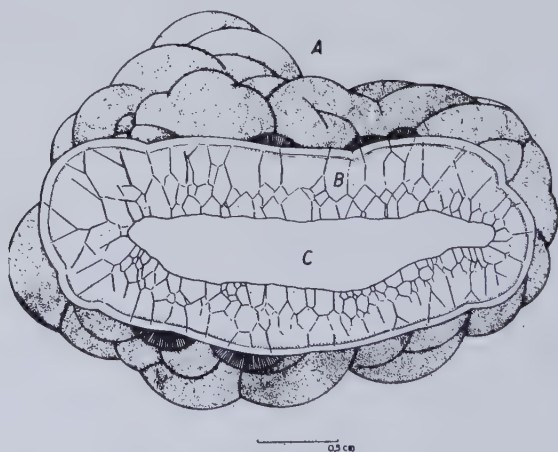


FIG. 3. Reniform honeycomb of zirconium oxide from the alluvial deposits of Serrote, Cascata, São Paulo.

In some botryoidal "combs" the repetition of fibrous layers gives the impression of a formation of hydrothermal origin. Between the thin concentric layers is concentrated microcrystalline material that is very difficult to resolve under the microscope. This material is all zircon.

Figure 3 shows a typical mammillary "comb." Some of the knobs are clearly fibrous in structure. Below the rounded protuberances there occurs a non-fibrous material which breaks in fragments with plane faces

(B, Fig. 3). The central part (C) is composed of massive, microcrystalline material. Under the microscope, the fibers show high order interference colors and parallel extinction. From microscopic study of several thin sections, we were able to determine that isolated "combs" are biaxial, with the acute bisectrix normal to the length of the fiber.

A typical narrow vein in altered nepheline syenite is zoned as follows: at the contacts are two symmetrical zones of fibrous, fan-like individuals; in the center occur globular concretionary masses with a similar radial structure; and between these occur the formless masses of zircon. This structure is common in the "combs" of fibrous-radial material. One of the more unusual fibrous-radial types is composed of a globular mass of acicular crystals which are encrusted by idiomorphic crystals of zircon. Ore of this type is found approximately 17 km. from Poços de Caldas on the road to Parreiras. Narrow veins, rich in cavities and druses, occur here in a strongly altered syenitic rock. From the structure of such veins it appears that the fibrous zirconium oxide crystallized first on the vein walls, and zircon later was precipitated in idiomorphic form in the centers.

The "combs" and especially the fibrous-radial material clearly show signs of alteration. They form compact, dark mammillary masses, difficult to break; and also masses that are clearer and less coherent but in which one can still recognize the acicular crystals; and finally, earthy masses, friable and clear in color. Between these three stages of alteration, all intermediate types are encountered. Probably the loss of color is due to the leaching of iron and manganese.

Another characteristic of the dark compact "combs" is exfoliation. Layers of uniform thickness peel off the surface of each protuberance. The exfoliated layers are of various colors and are lighter and less coherent than the rest of the material. In knobs in which three or more layers of exfoliation are present, one can easily note that the bleaching becomes more marked progressively outward. Moreover, these layers appear to have been preformed in the "comb," since it is possible to distinguish them there, due to their difference in color.

Associated materials (Caldasite)

The "caldasite," or associated material, is the chief vein ore. It is usually of ashy color and is very heavy. In masses of somewhat friable microcrystalline ore one encounters scattered idiomorphic crystals of green and brown zircon.

The relations in hand specimens seem to indicate that the fibrous zirconium oxide must have been the first to form, and that subsequently at its expense zircon was formed by means of silica-rich solutions. This

process is essentially a replacement of zirconium oxide by zircon. One can find relicts of fibrous-radial material within the zircon. Figure 4 offers evidence in support of this theory. In this ore specimen, which is cut normal to the direction of the fibers, one can see veinlets of microcrystalline zircon (A), cutting across masses of oxide (B).

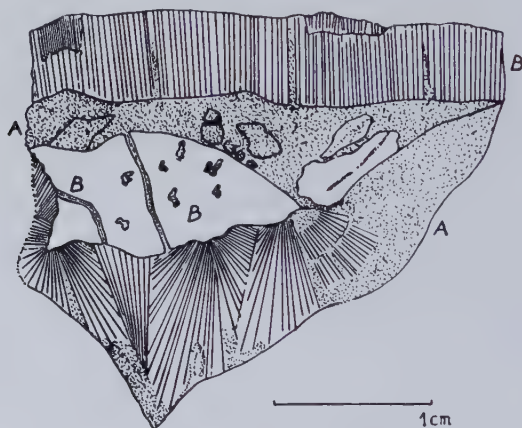


FIG. 4. Veinlets of fine-grained zircon (A) transecting zirconium oxide (B).

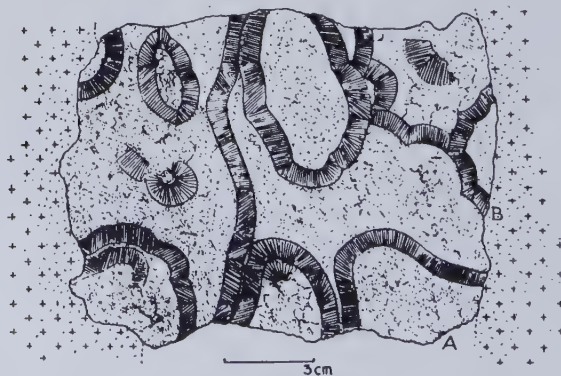


FIG. 5. Vein of "caldasite" in weathered source rock.

In another type of "caldasite" crystals of zircon encrust the walls of little geodes that occur in a homogenous mixture of the silicate and oxide.

Figure 5 shows "caldasite" in the altered source rock. In the center of the veins one may find pieces of nepheline rock cemented by zirconium material.

PHYSICAL AND CHEMICAL PROPERTIES

The large, translucent or nearly opaque brown zircons from the weathered augite syenite consist of zirconium orthosilicate. The gray "combs" with the earthy fracture are opaque, isotropic, and amorphous, as shown by x-rays. The densities vary between 4.6 and 4.8. After heating to 1100° C. the powdered material loses about 2 per cent of water, the density increases to 5.2, and the color changes to reddish-brown. It contains between 70 per cent and 90 per cent or more ZrO_2 , about 1 per cent TiO_2 , iron and some silica.

The dark brown, nearly black "combs," called "zirkonglaskoepfe" (zircon glass-heads) by the German authors (22, 23) differ little in composition from the amorphous material. Their density ranges from 5.0 to 5.3 and does not change after heating to 1100° C., although they also lose up to 2 per cent water. A spectrochemical analysis, made in the Technological Institute of Pesquisas, São Paulo, through the kindness of Miss Yolanda Monteux, showed the material to contain some manganese. This was chemically determined to be of the order of one part in twenty thousand, and maybe responsible, at least in part, for the color.

The small, translucent to transparent zircons associated with the crystalline variety of the oxide consist of practically pure zirconium orthosilicate.

Columbium, tantalum, and thorium were not found, either by chemical or by spectrochemical analysis. Hafnium was shown to be present in all samples examined by means of spectroscopic analysis. Chemical identification of hafnium by partial separation from zirconium was possible. From a hot 20 per cent sulfuric acid solution, to which sodium or magnesium sulfate is added nearly to saturation, fractional precipitation of a well flocculated, easily filtered zirconium phosphate of varying composition, containing neither titanium nor iron but larger amounts of hafnium than the original solution, is easily obtained by adding small quantities of phosphoric acid. It seems that the hafnium content in the "combs" is generally low, of the order of one to three per cent HfO_2 of the total $\text{ZrO}_2 + \text{HfO}_2$ present, and slightly higher in the zircons associated with the oxide. The hafnium content in the altered brown zircons from the country rock was not determined, but this was shown to be very low by Hevesy and Würstlin (11).

Solution of the finely ground oxide is accomplished rapidly by heating in a Pyrex beaker over a Téclu or Méker burner with sodium sulfate and an excess of concentrated sulfuric acid. Complete solution takes place within about half an hour. Zircon is dissolved without difficulty by fusion with sodium metaborate (fusion mixture, borax and sodium carbonate,

previously fused, crushed and ground), and consequent treatment with hydrochloric acid, or with hot methyl-sulfuric acid (concentrated sulfuric acid and methanol in equal parts).

The separation of iron and aluminum may be accomplished by adding the previously reduced solution containing tartrate to an excess of an alkaline solution of sodium cyanide. Final purification of zirconium and hafnium salts is possible by precipitation with ether from strong hydrochloric acid solutions. A crystalline, easily filtered precipitate forms, similar to that obtained with aluminum chloride solutions and ether. Iron remains in solution.

ORIGIN

The zirconium ore of Poços de Caldas is of hydrothermal origin. The majority of studies, both Brazilian and foreign, have arrived at this conclusion.

In our opinion, the following stages can be recognized: first, the formation, either by magmatic segregation, or by reaction, of the essential minerals of the alkaline rocks of the region, orthoclase, nepheline, aegirine, augite, sphene, melanite, sodalite, wollastonite, magnetite, biotite, hastingsite, scapolite, natrolite and muscovite. With these occur the complex silicates of zirconium: rosenbuschite (1), eudialyte (1), astrophyllite (1), lâvenite (15), eucolite (15) and very likely zircon.

According to Barbosa (1), rosenbuschite and astrophyllite are always poikilitic in texture and occur in foyaites and phonolites, but eudialyte is restricted to foyaites and coarse-grained rocks, where it may form high local concentrations. In addition to these zirconiferous minerals, we should recall that very probably acmite, a mineral extremely common in the nepheline rocks of the region, may also have been a source of zirconium. This mineral generally contains an important amount of zirconium. Probably the zirconium minerals were destroyed or attacked chemically by the hot, rising solutions, and the zirconium may have been precipitated in fissures in the highest zones, or even within the zone of attack itself, in the form of stable minerals (the oxide and silicate). By the action of weathering, the rocks bearing these mineralized veins were destroyed, thus permitting the accumulation of alluvial and eluvial deposits.

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NEW DATA ON SCHROECKINGERITE¹

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AND MAURICE J. PETERSON⁴

ABSTRACT

Schroeckingerite (dakeite) contains fluorine in a sufficient quantity to be calculated as an essential part of the formula. The previous value given for Na₂O is high, as is evidenced by a new analysis supported by comparative spectrograms. The mineral from the Wyoming type locality occurs in a partly indurated arkose, as well as in gypsite.

INTRODUCTION

Schroeckingerite, described as a hydrated carbonate and sulfate of calcium, sodium and uranium, is known only from two localities—Jachymov (Joachimstal), Czechoslovakia, and near Wamsutter, Wyoming. Due in part to its unusually complex composition and restricted occurrence, schroeckingerite has had a turbulent mineralogical history. It was first described from Jachymov by Schrauf⁵ as a hydrated uranium-calcium carbonate on the basis of a qualitative analysis. The presence of sodium and sulfate was subsequently recognized by Nováček,⁶ who studied the Jachymov material and by Larsen and Gonyer⁷ who described the Wyoming occurrence. The name dakeite was assigned to the Wyoming material, which at the time was believed to be a new mineral. Nováček showed that dakeite was identical with schroeckingerite and the former name has since been discredited. It is the purpose of this paper to show that the chemical composition of schroeckingerite is even more complex than was recognized by previous investigators.

CHEMISTRY OF SCHROECKINGERITE

During a routine visual spectroscopic examination of a prospector's sample of schroeckingerite submitted to this laboratory, it was observed

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⁵ Schrauf, A., Schröckingerit, ein neues Mineral von Joachimsthal: *Min. Mitt.*, Heft II, 137–138 (1873).

⁶ Nováček, R., The identity of dakeite and schroeckingerite; *Am. Mineral.*, **24**, No. 5, 317–323 (1939).

⁷ Larsen, E. S., Jr., and Gonyer, F. A., Dakeite, a new uranium mineral from Wyoming: *Am. Mineral.*, **22**, No. 5, 561–563 (1937).

that the mineral contained fluorine. Consequently, a sample of schroeckingerite from the Wyoming type locality described by Larsen and Gonyer and by Dake⁸ was obtained from the U. S. National Museum. All the data for schroeckingerite given in this paper were determined on the museum sample. Visual spectroscopic analysis of carefully picked ma-

TABLE 1. ANALYSIS OF SCHROECKINGERITE FROM WYOMING

Analysis		Molecular Ratios		Theoretical Composition
CaO	18.14	0.3245	6× .0541	18.91
Na ₂ O	3.63	.0587	1× .0587	3.49
UO ₃	31.44	.1091	2× .0546	32.21
CO ₂	14.20	.3227	6× .0538	14.86
SO ₃	9.17	.1146	2× .0573	9.02
F	2.15	.1131	2× .0565	2.14
H ₂ O	20.15	1.1200	20× .0560	20.27
R ₂ O ₃	0.95	—	—	—
SiO ₂	0.08	—	—	—
99.91				100.90
.90 Deduct 0=2F				-0=2F .90
99.01				100.00

TABLE 2. ANALYSES OF SCHROECKINGERITE

	I	II	III
CaO	18.14	18.31	19.1
Na ₂ O	3.63	7.31	Not determined
UO ₃	31.44	30.27	32.4
CO ₂	14.20	13.71	Not determined
SO ₃	9.17	9.61	9.1
F	2.15	—	—
H ₂ O	20.15	19.95	20.2
Insol.	—	1.05	0.4
R ₂ O ₃	0.95	—	—
SiO ₂	0.08	—	—
99.91		100.22	—
Deduct 0=2F .90			
99.01			

⁸ Dake, H. C., The dakeite locality—Wyoming, *The Mineralogist*, **6**, No. 3, 7-8 (1938).

terial showed fluorine to be a constituent of the museum sample as well as the prospector's sample. Fluorine was not detected spectroscopically in samples of the barren host rock. As a result of these preliminary studies, a larger sample was selected for a complete chemical analysis. The sample was carefully examined with both the binocular and petrographic microscopes and found to be essentially free of impurities. A complete analysis made by the Metallurgical Division staff is given in Table 1, with the molecular ratios and theoretical composition.

The analysis reported in this paper (I) and those of Gonyer (II) and Nováček (III) are offered for comparison in Table 2. These represent the only quantitative analyses of schroeckingerite that have been published to date.

The significant differences between analyses (I) and (II) are the absence of fluorine in the latter and a discrepancy in the percentage given for soda. The value 3.63 given in (I) is the average of two determinations which gave 3.57 and 3.69 per cent Na_2O , respectively.

Gonyer's analysis (II) shows approximately twice the quantity of soda found by the writers (I) and Nováček's analysis (III) unfortunately does not include a soda determination.

To confirm the chemical values of 3.63 per cent Na_2O and 2.15 per cent F in schroeckingerite reported in analysis (I), four synthetic standard samples were prepared. A base mixture of 47.0 per cent U_3O_8 and 53.0 per cent CaCO_3 was used to approximate the composition of schroeckingerite. Additions of Na_2SO_4 to the base mixture were made to obtain samples containing 3.6 per cent and 7.3 per cent Na_2O , respectively. Likewise, additions of CaF_2 were made to the U_3O_8 - CaCO_3 mixture to obtain samples containing 2.0 per cent and 5.0 per cent fluorine. All samples were prepared by hand mixing and grinding with a boron carbide mortar and pestle.

Fifteen milligrams of each of the standard samples and the schroeckingerite were carefully weighed on a microbalance, transferred to a 3/16" diameter graphite electrode and arced in a 250-volt direct current arc. Spectrograms were recorded by means of a 3-meter grating-type spectrograph. The standard samples containing 3.6 per cent and 7.3 per cent Na_2O and schroeckingerite were spectrographed on one plate. A separate plate was used to spectrograph the fluorine standards and schroeckingerite.

Figure 1 shows the sodium doublets at 5889.97 and 5895.93 and 5688.0 and 5682.8 Å. The Na lines in the spectrogram of schroeckingerite are quite similar to the 3.6 per cent Na_2O standard. Conversely, the Na lines in the 7.3 per cent Na_2O standard are of much greater intensity than those in the schroeckingerite spectrogram.

Na lines

5895.93 Å
5889.97 Å

Na lines

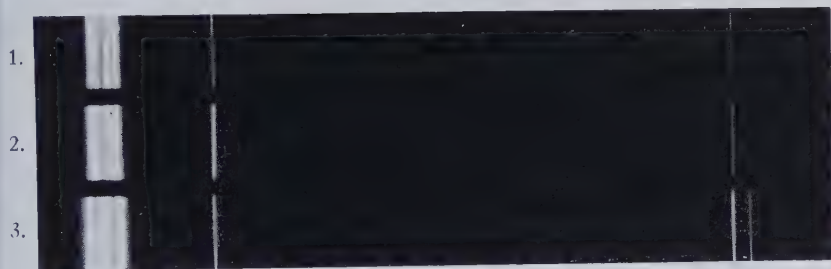
5688. Å
5682.8 Å

FIG. 1. Spectrograms of (1) schroeckingerite, (2) synthetic mixture of U_3O_8 and $CaCO_3$ containing 3.6 per cent Na_2O and (3) the synthetic mixture with 7.3 per cent Na_2O .

Figure 2 shows the CaF band, with its head at 5291Å for schroeckingerite and the two standard samples containing 2.0 per cent and 5.0 per

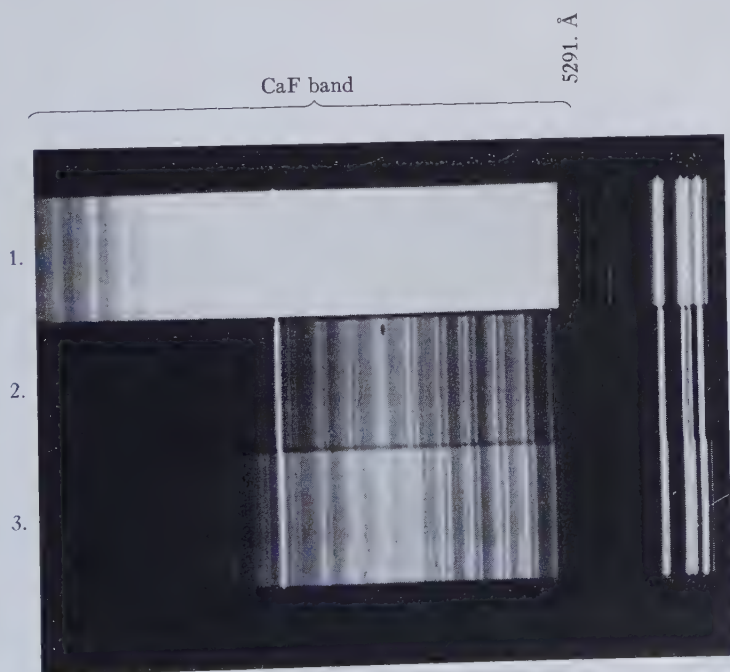


FIG. 2. Spectrograms of (1) a synthetic mixture of U_3O_8 and $CaCO_3$ containing 5.0 per cent fluorine, (2) schroeckingerite and (3) the synthetic mixture containing 2.0 per cent fluorine.

cent fluorine. Comparison of the intensities shows that the CaF band for schroeckingerite agrees with that of the 2.0 per cent standard.

Based on the analysis made in this laboratory, the composition of schroeckingerite may be written as: $\text{Ca}_3\text{Na}[\text{UO}_2(\text{CO}_3)_3(\text{SO}_4)\text{F}] \cdot 10\text{H}_2\text{O}$.

PETROGRAPHY

The physical and optical properties of schroeckingerite recorded by the writers are essentially those published by Larsen⁷ for "dakeite." The mineral is greenish yellow and occurs in micaceous, pseudohexagonal plates showing a perfect basal cleavage. It fluoresces a vivid yellow-green under the ultraviolet lamp. Before the Geiger-Mueller counter, it shows only faint radioactivity. The following optical properties were recorded:

	n
X (colorless to very pale yellow)	1.489 ± 0.002
Y (pale greenish yellow)	1.541 ± 0.002
Z (pale greenish yellow)	1.541 ± 0.002
2V = near 5° (—)	

Nováček and others have pointed out that schroeckingerite may be hexagonal, uniaxial and the small separation of the isogyres is due to strain. Numerous interference figures examined by the writers all showed a slight separation of the isogyres. As individual grains do not show any marked wavy extinction it is assumed that the mineral is biaxial.

Larsen notes that the mineral occurs as rounded to elongated pisolites, up to a centimeter in diameter in gypsite. He reports that "the gypsite is made up mostly of small crystals of gypsum with a little sand and the dakeite." The locality is further described by Dake,⁸ who reports that the "dakeite" occurs in a gypsite bed having an average thickness of three feet. The bed is overlain by a "disintegrated granite" and underlain by "loosely consolidated sandstones and volcanic ash."

The samples obtained from the U. S. National Museum indicate that the schroeckingerite is not confined to the gypsite alone but also occurs in the "disintegrated granite" of Dake. A composite of several samples of the host rock examined in this laboratory showed a rather heterogeneous mineral assemblage and a surprisingly low gypsum content. The principal constituents, aside from schroeckingerite, included albite-oligoclase, microcline, quartz, and kaolinite. Accessory minerals represented included chlorite, epidote, hornblende, muscovite, gypsum, and rutile. A composite of several samples from which the schroeckingerite was removed analyzed only 0.02 per cent S, indicating a very low gypsum content. The host rock examined here is best classified as a partly indurated arkose.

An x -ray powder diffraction pattern of schroeckingerite obtained by H. F. Carl with an automatic recording x -ray diffraction spectrometer is given in Table 3.

TABLE 3. X-RAY POWDER DIFFRACTION PATTERN OF SCHROECKINGERITE FROM WYOMING

I/I_0	d_{hkl}	I/I_0	d_{hkl}
5	14.5	1	3.32
1+	8.3	1	3.24
10	7.2	1 broad	3.1
1+	5.62	6	2.88
1+	5.45	1	2.78
1	5.32	<1	2.71
6	4.81	<1	2.63
1	4.26	1+	2.40
1+	4.18	<1 broad	2.30
1	4.06	<1	2.12
1	3.61	3	2.05
1	3.37	1+	1.80

I/I_0 =relative intensity.

d_{hkl} =interplanar spacing.

ACKNOWLEDGMENTS

This investigation was conducted under the immediate supervision of Alton Gabriel, to whom the writers are indebted for valuable criticism and advice.

The writers wish to thank E. P. Henderson and James Benn, both of the U. S. National Museum, for furnishing the samples of schroeckingerite, Morris Slavin of the Metallurgical Division for helpful suggestions, and R. D. Dwiggins, formerly of the Metallurgical Division, for participation in the analytical work.

PRESENTATION OF THE ROEBLING MEDAL OF
THE MINERALOGICAL SOCIETY OF AMERICA
TO PAUL NIGGLI*

EDWARD H. KRAUS,
University of Michigan, Ann Arbor, Michigan.

Ten years ago at the meeting of this Society in Washington the first Roebling Medal was presented to Charles Palache, the Dean of American Mineralogists and for many years a close friend of Colonel Washington A. Roebling. Since then four other mineralogists from the United States and one from Great Britain have been recipients of the medal. Meeting today in Ottawa, the capital of the Dominion of Canada with its many close ties to the Old World, it is indeed fitting that a European should be selected to receive the award on this occasion. It is also very appropriate that the recipient should be a native and resident of Switzerland, the country which for centuries has been noted for the industry, efficiency, and integrity of its citizens and has always stood as a mighty bulwark for science, democracy, and international good will.

Paul Niggli was born at Zofingen, Switzerland, on June 26, 1888. His early education was obtained in the city of his birth and at near-by Aarau. In 1907 he entered the Eidgenössische Technische Hochschule in Zürich, from which he was graduated as an engineer in 1912. He then studied for a short period at the Technische Hochschule in Karlsruhe, Germany, and on his return to Switzerland passed the examinations at the University of Zürich for the degree of Doctor of Philosophy.

At the institutions in Zürich and Karlsruhe he was privileged to study with many eminent scientists. These included the mineralogist and petrographer Ulrich Grubenmann, the geologist Albert Heim, the chemists Richard Willstätter, G. Bredig, and E. Baur, and the physicists Pierre Weiss and Albert Einstein. Having devoted much time to physics and physical chemistry, it was quite natural that he should wish to spend some time at the then recently organized Geophysical Laboratory in Washington, where in 1912-13, as one of the first Europeans to do so, he engaged in research. On his return to Zürich, frequently called the Athens of Switzerland, he qualified as a Privat-dozent at the University. From 1915 to 1920 he held appointments at the German universities in Leipzig and Tübingen. He then became professor of mineralogy and petrography in Zürich, as the successor to his distinguished teacher, Professor Grubenmann. It should be stated that in Zürich the Technische Hochschule and

* Presented at the annual luncheon meeting of the Society which was held on December 20, 1947, Ottawa, Canada.

the University are very closely integrated, and some staff members serve both institutions, as does Professor Niggli.

In 1920, when Dr. Niggli was appointed professor, Zürich was widely recognized as a leading center for the study of the earth sciences. This was due in large measure to the many important and enduring contributions made by his distinguished predecessors and teachers, notably Kenngott, Grubenmann, and Heim. To maintain this high reputation and, if possible, to increase the prestige of the institutions in Zürich was no small task that devolved upon Professor Niggli. Possessed of an apparently limitless store of energy and industry and with an excellent preparation and experience in the newer phases of science as related to mineralogy and petrography, he soon demonstrated that he was equal to this task.

Professor Niggli's bibliography includes nearly two hundred papers and about fifteen books. In these publications, he clearly reveals his comprehensive grasp not only of the earth sciences, but also of cognate fields. This is amply illustrated by his studies dealing with fundamental crystallographic and theoretical structural concepts, stereochemistry as applied to crystals and minerals, ore deposits, the constituents and products of the magma, igneous and metamorphic rocks, paragenesis of minerals, the minerals of the Swiss Alps, and the science of snow and avalanches, to mention some of the general subjects. By applying the newer methods and viewpoints as developed by physical chemistry and modern physics to crystallographic, mineralogic, and petrographic problems, he has in many of his publications opened new avenues of approach and has thus influenced scientific thinking and interpretation.

Along with this unusual scientific activity, Professor Niggli served from 1921 to 1940 as editor of the *Zeitschrift für Krystallographie und Mineralogie* founded by Paul Groth at Strasbourg in 1877. Because of the shift in emphasis which had taken place in crystallographic and mineralogic research, the name of the journal was changed to the *Zeitschrift für Krystallographie* with the sub-title *Krystallogometrie, Krystalphysik, Krystalchemie*. Beginning with the sixtieth volume in 1924, the distinguished physicists Max von Laue and P. P. Ewald, and the well-known physical chemist K. Fajans were associated with him as editors. During Dr. Niggli's incumbency as editor, forty-six volumes of the *Zeitschrift* were published.

Professor Niggli has not only achieved an eminent international reputation as a scientist and editor, but he has also demonstrated exceptional ability as an administrator. This is evidenced by the fact that he has served as rector of the Technische Hochschule for three years (1929-32) and of the University of Zürich for two years (1940-42). Last year

he was chairman of the commission on arrangements for the two hundredth anniversary of the founding of the Naturforschende Gesellschaft of Zürich, which was held in September, 1946, and as president of that organization he presided at the sessions. Moreover, he is president of the Geotechnical Commission and a member of the Geological Commission of Switzerland. Service on important educational committees of the University and of the Canton of Zürich must also be mentioned.

Professor Niggli's achievements have been recognized by the conferring of honorary degrees upon him by the Universities of Geneva, Budapest, and Sofia, and the Technische Hochschule in Stuttgart. In addition, he has been elected a fellow or corresponding member of approximately twenty of the world's leading learned and scientific societies, including the Mineralogical and Geological Societies of America. He is indeed a citizen of the world.

We all rejoice that Professor Niggli could be present at this meeting, which is truly of an international character. His attendance was made possible by a substantial grant from the American-Swiss Foundation for Scientific Exchange, Inc.

Paul Niggli.—In recognition of the many significant and abiding contributions which you, as teacher, investigator, author, and editor, have made to the advancement of the various branches of science represented by this society, it is indeed a great privilege and honor, on behalf of the Mineralogical Society of America, to present to you the Washington A. Roebling Medal.

ACCEPTANCE OF THE ROEBLING MEDAL OF THE MINERALOGICAL SOCIETY OF AMERICA

PAUL NIGGLI,

Eidgenössische Technische Hochschule, Zürich, Switzerland.

The Roebling Medal, which The Mineralogical Society of America has been pleased to confer upon me, is indeed a unique distinction for a mineralogist. This presentation marks the second time the Medal has gone overseas and the first time to go to Switzerland. Professor Kraus has referred to the work of the Swiss mineralogists and geologists and to me in most flattering terms. Small wonder, then, that at this moment I should feel not only thankful to you, who have thus honored me, but embarrassed as well. I cannot but think that individual effort, when it shows a certain continuity and springs from real pleasure in the subject, may easily be overrated.

And so I should like on this so memorable an occasion for me to define in some measure what seems to me the special charm of the science we all serve. Some 40 years ago when I decided to take up the study of mineralogy, men who knew that I liked to grapple with a problem asked me why I had not chosen one of the so-called fundamental sciences, such as chemistry or physics. Minerals were, they said, for the most part already well known, and the general knowledge of the lithosphere was so far advanced as only to leave routine work to be done. The development of our science during the last 40 years has amply shown how far amiss such opinions were. And yet even today, and in spite of the rapid advance of crystal chemistry as a new connecting link between different sciences, mineralogy seems to lie off the road, since "speed," "actuality," "rationalization" are the order of the day. Perhaps this is because a comparatively tranquil atmosphere has surrounded our work. To understand the essential difference between our style of research and that prevailing in other sciences, we must define more clearly the very nature of the latter.

The progress of chemistry and physics has been made possible by observation, analysis, and experimental and mathematical treatment of natural phenomena. But happenings in nature, such as thunderstorms or avalanches in the spring time, were divided into a number of separate processes, each of which could be satisfactorily studied in the laboratory under precisely defined conditions. Thus separated from their natural context, they provided the basis of chapters in Electricity, Mechanics, and Physical Chemistry.

If a chemist or physicist is asked today about the details of the formation of a rock or mineral paragenesis, he will indicate some general laws, but at the same time point out that the influencing factors are far too



PAUL NIGGLI, RECIPIENT OF THE ROEBLING MEDAL OF THE MINERALOGICAL
SOCIETY OF AMERICA

numerous and the prevailing conditions too vague for an exact answer. He feels little interest in the intricate natural combination of processes which he for his part is accustomed to study separately, or at least to combine according to his own desire. The laboratory study has become for him the surroundings in which he receives the impetus and inspiration for his work.

These sciences have often been called the exact ones because they endeavor so to simplify and generalize the problems so that comparatively unequivocal deductions can be made. Research that is directed toward the unaltered conditions found in Nature (in the lithosphere, for example) that strives to give these conditions a scientific formulation and to understand them as the result of certain processes, is generally called a descriptive science. This is because axioms and definitions are replaced by descriptions of what Nature provides. But it is certainly not true to say that such descriptions exhaust the scope of our science. To the same extent as in physics or chemistry, it studies processes and properties and strives to understand the present state of things as derived or still in process of derivation from former states. But what is characteristic of the so-called descriptive sciences is their constantly maintained effort to reach an understanding of the natural phenomena as a whole, influenced and guided as they are by a multiplicity of factors.

The mineralogist and petrographer can never approach his problems from a one-sided standpoint. As a geologist, geophysicist, and geochemist, he must study the sites chosen by Nature for forming minerals and mineral deposits. What concerns him most is the question how this product of Nature came to be, what ultimate causes (irrespective of chemistry and physics) gave it its peculiar aspect and relationship to other occurrences. The physicist and chemist who is only interested in certain fundamental phenomena runs the risk of undue specialization. On the other hand, the mineralogist, petrologist, geologist, and biologist, for whom every natural factor is of importance and who should, therefore, be accurately informed about all of them, can, very often, not meet the requirements made upon him. Much that he needs for his synthesis must be accepted by hearsay, which easily leads to diletantism.

Thus, both lines of research have their danger, though of course, the fundamental differences that have been sketched by no means coincide with an aptitude for any one subject or line of teaching. Many highly meritorious teachers and researchers in mineralogy and petrography have restricted themselves to very narrow fields and have never felt the urge to apply themselves to any particular occurrence in Nature. On the other hand, there have been physicists and chemists who never lost sight of the natural interrelations. But on the whole, the fact remains that the

work of the mineralogist and petrologist starts from a study of Nature and is an attempt to apply the teachings of all fundamental sciences to his own very special problems. And this seems to me at least the peculiar, in fact, incomparable, attraction of the earth-sciences.

In some remote valley of the Alps and among the steep rocks we find signs of mineral fissures formed during the period of compression of the earth's crust and of mountain building. Carefully opened, the interior of the fissure displays a maze of crystals, wonderfully regular in shape. We attempt to unravel the laws governing the structure of these products of Nature, structures which require magnifications of a hundred million times to be made visible. And with their help the processes of crystallization and the development of crystal forms are made accessible to our understanding. Other questions arise which go beyond the formation of the individual occurrence and relate to mineral paragenesis in general, for instance the source of the solutions from which the crystals have separated according to physical-chemical laws. These in turn lead to a study of the rocks in which the mineral fissures were formed and further to the rock-forming processes and geochemical laws which many millions of years ago led to the formation of this part of the lithosphere that during the course of the Earth's history has again and again undergone changes and entered into characteristic reactions with the exterior forces.

Immense vistas thus appear before us, as soon as we attempt to comprehend in its historic significance even so small a portion of the inorganic world around us. Surely this task of reconstruction must always seem a fascinating one, even though we are aware that the picture we construct carries no certainty with it but merely a probable or possible sequence of events. Our activities may be compared with those of an artist who from many separate impressions creates a painting in which form and color are but parts of a whole, but whose harmony conveys an essential truth.

The stress, thus laid on the historical and artistic aspects of our science, may perhaps evoke the question whether such activities are of any practical value. Personally, I consider this question misplaced. The urge toward understanding the world around us is not one that can be judged by material values and from the point of view of its usefulness. The times in which we live have made it doubtful whether the progress of technical science has been well or badly applied. But it is clear that every scientific achievement must have an influence on our daily lives and that it would be absurd not to make use of the results of our labors in shaping the pattern of the surroundings in which we live. Our sciences are no exceptions in this respect. Nor do they merely show us where our raw materials are to be obtained. The increasing importance of complicated building and construction materials calls for widely comprehensive viewpoints that

are essential to the mineralogist and petrographer. It does not suffice to classify an industrial material according to its chemical composition or physical behavior under simple conditions. Internal structure, micro- and macro-structures, behavior under influence of variously combined factors in tests of short and long duration, all these and many other details must be given conscientious consideration before a useful characterization can be arrived at.

The mineralogical style of research is beginning to make headway in these connections and, as in medicine, so also in the study of materials, scientists with a broad outlook are increasingly being called upon to supplement the work of the specialists. The value of correlations based on a knowledge of the constitution as a whole is thus becoming increasingly appreciated.

The aims man sets for himself are ideals he can never achieve. That, of course, is true also for mineralogical and petrographic research. How gratifying is it, then, when the striving for truth finds recognition, notwithstanding the errors that have crept in. Thus, it is, I feel, not through what I have achieved, but at most by loyalty to what I consider to be the fundamental principles of our science that I can in any way merit the honor you have bestowed on me, which moves me so deeply. For such time as may still be given me, the Roebling Medal will always be an incentive to further research.

I extend to you my heartfelt thanks, and my thanks go also to our common inexhaustible Science, which even in the darkest days of our history has never failed to enrich us.

MEMORIAL OF GREGORI AMINOFF

TOM. F. W. BARTH, *University of Chicago, Chicago, Illinois.*

Professor Gregori Aminoff, mineralogist and crystallographer, one of the great scholars of Sweden, died on February 11, 1947. Rarely has a scientist had a broader field of interest. He was well educated, accomplished and productive in the fine arts as in science; *non omnis moriat*.

Gregori Aminoff was born at Stockholm in 1883 and took his first University examination at Uppsala in 1905. For the following ten years, however, he turned to the cultivation of the fine arts for which he was especially gifted—music and painting. In Paris he studied with Matisse, in Italy he further developed his skill in landscape and portrait painting.

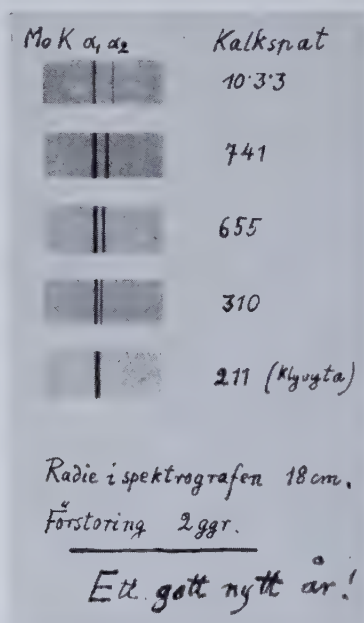
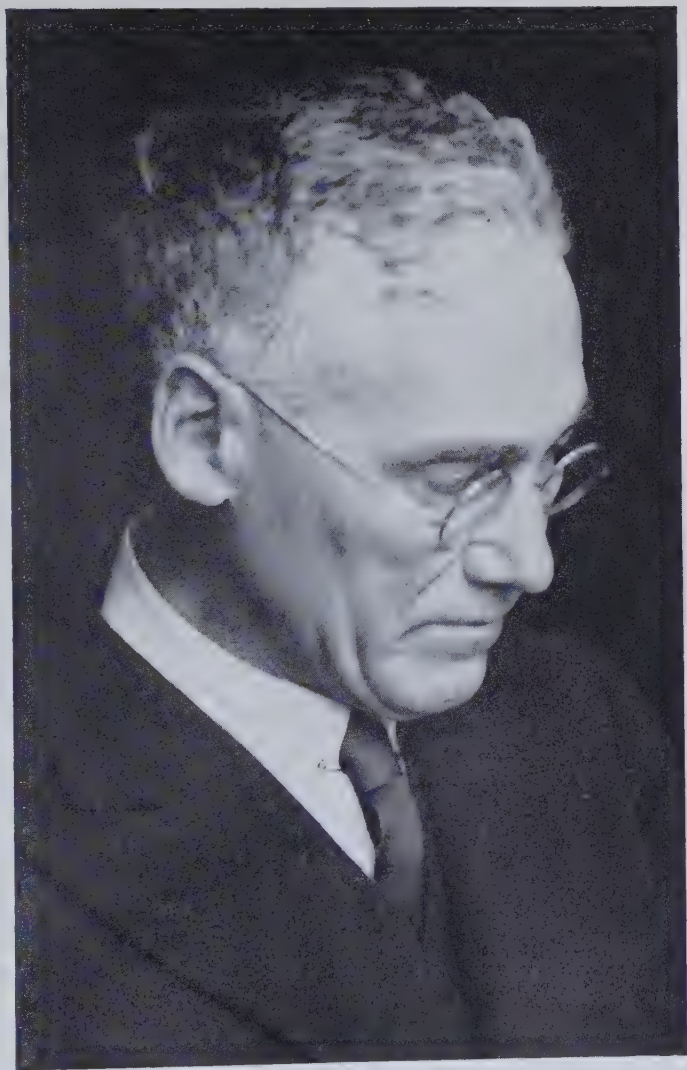


FIG. 1

His return to science was abrupt, and in 1918 he received his doctor's degree. In 1923 he became the successor of Hjalmar Sjögren, professor and director of the mineralogical division of the Riksmuseum at Stockholm. It is amusing to note that this was the third position he had applied for at the Museum. A draftman's job was his first ambition, assistant curator his second. The first two applications were turned down.

In his numerous publications are reflected his versatility and comprehensive knowledge of working methods and theory in all fields of modern



GREGORI AMINOFF
1883-1947

mineralogy. He started the study of crystal structures with x -ray methods at Stockholm's Högskola as early as 1918, and subsequently he pursued this line of research, which at that time was in its infancy, with great ardor and success. He obtained results of great general and theoretical interest in those early days of crystal structure work, in investi-

gating and interpreting the atomic structures of twinned crystals, and of unknown structures. Likewise Aminoff's work on the evaporation phenomena in crystals, and especially his study of the diffraction phenomena of electron rays from crystals are among the finest works of crystal physics. Of great help in his advanced crystallo-physical work was the active collaboration of Dr. Birgit Broomé, herself an accomplished physicist, now his widow. In later years he and his wife devoted much of their time developing new and better methods in *x*-ray spectroscopy and its application to chemical mineralogy. This field of research is still altogether unknown in America, but for more than 20 years the *x*-ray emission spectrograph has been a routine tool in Aminoff's laboratory. Shortly before his death he devised a spectrograph based on new principles, especially designed for chemical mineralogy. At his death he was experimenting with high dispersion technique, as can be seen from the spectra reproduced by him as a New Year's card and mailed to his friends (Fig. 1). After his death his wife has continued the work and carried out the construction of the instrument.

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MEMORIAL OF JOSEPH PETER CONNOLLY

L. C. GRATON, *Harvard University, Cambridge, Massachusetts.**

In a man who has risen to prominence it is especially refreshing and heartening in these days to find the steadfast exemplification of strength joined with fairness and tolerance, persuasion fortified by sincere convictions, and authority coupled with friendliness and modesty. Such a man was Joseph Peter Connolly. With simple directness and eager devotion he discharged each obligation in such manner that increasing responsibility gravitated to his willing but uncovetous hands and spontaneously elevated him to successive levels of opportunity and influence. Sterling character and the true scientist's deep appreciation of cause and effect held him beyond pressure of propaganda or lure of publicity.

Born in Cleveland, Ohio, on November 15, 1890, the only son of Peter A. and Bertha (Orwig) Connolly, he attended the public schools of his city, and in 1908 entered Oberlin. Early in his sojourn there he became deeply interested in mineralogy and geology, under the stimulating guidance of E. B. Branson. For two years after graduation in 1912 he worked in a manufacturing company. But science remained foremost in his mind, and in 1914 he entered the graduate department of the University of Missouri, again with Branson. Advanced study was combined with field investigation for the Missouri Bureau of Geology and Mines, and led to the Master's degree in June, 1915.

That autumn he began graduate work at Harvard, with emphasis in mining geology. With quiet application he perfected his background and began independent investigation, finding particular appeal in those genetic aspects of ore occurrence which are revealed by the mineralogical association. With work of such quality as to merit three scholarships, one for summer field studies, he was well advanced on a doctoral thesis when, in 1917, the call of war changed his plans. Small and slight in build, he enlisted as a private and entered the Motor Transport Corps; later he was commissioned as Second Lieutenant. Discharged from the Army as 1918 closed, he was immediately engaged as instructor in Economic Geology at Missouri.

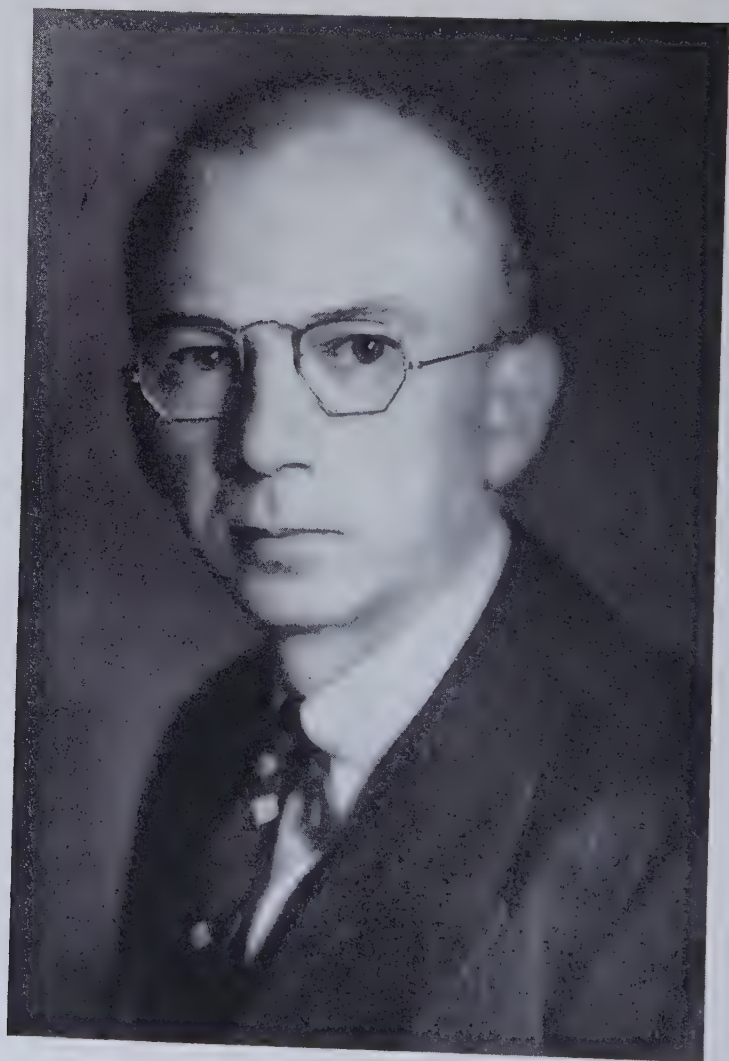
In September, 1919, at the age of twenty-nine, Connolly was appointed Professor of Mineralogy and Petrography at South Dakota School of Mines and Technology, where his mature career was destined to center. His service at that institution naturally divides into three periods, cor-

* For assistance in the preparation of this memoir, grateful acknowledgment is due to Dr. D. H. McLaughlin, President of Homestake Mining Company, and to Dr. E. L. Tullis, Professor of Geology at South Dakota School of Mines and Technology.

responding to growing proportions of administrative responsibility superimposed on his teaching and research.

During the early years, the instruction of geological nature was organized to serve the curriculum in Mining. Connolly so built up the content and quality of his teaching as to become recognized as the most effective and popular instructor in the Faculty. But he also was enabled to devote a substantial time to research. This and his summers were actively applied to investigation of the minerals and mineral resources of the Black Hills. The famed Etta mine and other mineral occurrences of the pegmatitic class were studied and discussed. Gold being the chief mineral product of the State, he recognized the need for restudy of the deposits of that metal. He gave careful attention to the great Homestake occurrence in contorted and metamorphosed pre-Cambrian sediments. But his special purpose there was to establish a basis of comparison with the neighboring gold deposits lying as siliceous replacements of dolomitic Cambrian beds. Of the latter he made extended investigation, by careful observation and precise mapping underground, and thorough study in the laboratory. Having earlier given much consideration to limestone replacement ores belonging in the high-intensity pyrometasomatic class, he possessed good standards for establishing the intensity-characteristics of these so-called refractory ores of the Black Hills. His conclusions, accepted as a doctoral thesis at Harvard in 1927, and published as a Bulletin by his own institution, were a constructive and sound contribution which would have been of great assistance to the local mines could it have appeared when they were in their prime several decades earlier. The outstanding by-product of this work was the presentation and clear analysis of evidence that these post-Cambrian (Tertiary) ores are unrelated in age and genetic environment to the Homestake deposit, which he convincingly dated as pre-Cambrian.

The second phase of Connolly's service to his School began in 1926. Notwithstanding his unassuming nature and his devotion to his own field, clarity of mind, sound judgment and capacity to cooperate had by then become so manifest as to lead to his appointment as Vice President of the School. The added duties inevitably directed less of his attention to field work, and more of it to the institution itself. President O'Harra and he carried into effect their long-desired plan of broadening the instruction centering around geology and establishing it as a Department. In collaboration with O'Harra, he published a comprehensive summary and analysis of the mineral wealth of the Black Hills. He greatly enlarged the Museum, especially in the direction of mineralogy. He continued with his own teaching; and he took increasing part in the regional and national organizations concerned with the mineral industry. But the



JOSEPH PETER CONNOLLY
1890-1947

broad administrative duties increased. On the death of Dr. O'Harra early in 1935, Connolly became Acting President.

With his accession to Presidency of the School in August, 1935, began the third stage of his service. Although he relinquished first the direction of the Geological Department and later his title of Professor of Geology, his deep interest in the subject and in the welfare of the Department was

manifested unceasingly. He led the Badlands Expedition in 1940 under the joint auspices of the National Geographic Society and his own institution. His writings, now addressed to a more general audience than before, continued to draw upon his geological background.

At the time Connolly became responsible for the administration of the School, appropriations were at a low level in consequence of the depression. His formula for meeting this situation was characteristic: constructive improvement of the standards of the School. He broadened the existing curricula by addition of departments further emphasizing the basic sciences. He was able to attract excellent men to the faculty and to perfect the cooperation and spirit throughout. Registration began to rise. From these solid grounds, his approach to the State Legislature could comport with the man's directness and dignity. Persuasion consisted in disclosing that the needs were in balance with the opportunities. Consistent increases in appropriation and spiritual support resulted. Besides many less tangible steps of strengthening, his term as President saw a substantial building expansion, and an increase of more than fifty per cent in the student body.

Accepting the national policy of permitting qualified engineering students to continue their training during the Second World War, Connolly exerted constant effort to hold this opportunity open at South Dakota. The new problems of expansion and readjustment of the post-war period came with the onset of a progressive illness. Without excuse or complaint he resolutely persevered in full activity for two years. With the understanding support of his wife he continued to face the days with high courage to the end. He died on October 7, 1947, at the age of fifty-six.

Connolly was a fellow of the Mineralogical Society of America, the Geological Society of America and the American Association for the Advancement of Science. He held membership in the Society of Economic Geologists and the American Society of Engineering Education. In the American Institute of Mining and Metallurgical Engineers he was National Chairman of the Committee on Mining Courses, and had been Chairman of the Black Hills Section. He participated actively in the South Dakota Academy of Science. He organized in 1944 the South Dakota Chapter of the Newcomen Society and was made State Chairman. In recognition of Connolly's efficient assistance in preparation for the stratosphere balloon ascents conducted by the Army and the National Geographic Society, he was made an Honorary Life Member of that Society. He was member or honorary member of the several academic honor fraternities.

Loyal service to his State and his community equalled the high regard

and respect in which he was held by the citizenry. A member of the Natural Resources Commission and of the Committee on Economic Development of the State, he took constructive part in expanding the welfare of the commonwealth. He was member, and later honorary member, of the Black Hills Council of Boy Scouts; member of the Rapid City Chamber of Commerce and of its Committee on Mining and Lumbering; member of the Rapid City Rotary Club and its president during 1939 and 1940; an original member of the State Committee of the U. S. O. He was Vice-President of the Rapid City Concert Association, and a vestry member of Emmanuel Episcopal Church. Genuine, generous and friendly, he was affectionately known as "Joe" Connolly. His death saddened the entire community.

Dr. Connolly in 1924 married Anne Ruth Lewis, former Registrar and Secretary of the School, whose sympathetic partnership through the years was an unfailing inspiration to him. She and their two sons survive him.

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MEMORIAL OF TERENCE THOMAS QUIRKE

CARLETON A. CHAPMAN, *University of Illinois, Urbana, Illinois.*

Terence Thomas Quirke was born July 23, 1886, in Brighton, Sussex, England. His father, a concert violinist of distinction and a violin teacher, had come to England from Ireland in the early 1860's. His mother was an accomplished pianist who, with her husband, gave over thirty annual concerts in Brighton.

Young Terence received his elementary schooling in private schools in Brighton and was later admitted to Bancroft's School in Woodford, Essex. At this public school (private school in the American sense) he received a fine training in preparation for university work. While at Bancroft's School, Terence won prizes in Scripture, free hand drawing, French, Latin, and fencing and won school letters in soccer and cricket. After graduation he hoped to be accepted in an officer's training school for the British navy but his eyes would not pass the test, and it was recommended that he spend a year in an open-air life to improve his myopic condition. He decided to go to a ranch in North Dakota and so in March, 1904, he left England. With limited financial resources and with no knowledge of manual labor, he was headed for a rugged life for which by birth, by education, and by temperament he was unprepared. Perhaps, one of the major accomplishments of his early days in America was the manner and rapidity with which he was able to readjust himself from his particular English status to a very humble life in a ranch house of whitewashed logs and dirt on the prairies of North Dakota. At the end of a year on the ranch, he decided to try his luck at other things, still planning to return to England in a year or two. He took a position as clerk with a steamboat company on the Missouri and Yellowstone Rivers. In this work, which lasted about a year, he became a good friend of Captain Marsh of Missouri River fame and developed a keen interest in the nature and behavior of streams in flood as well as in other stages.

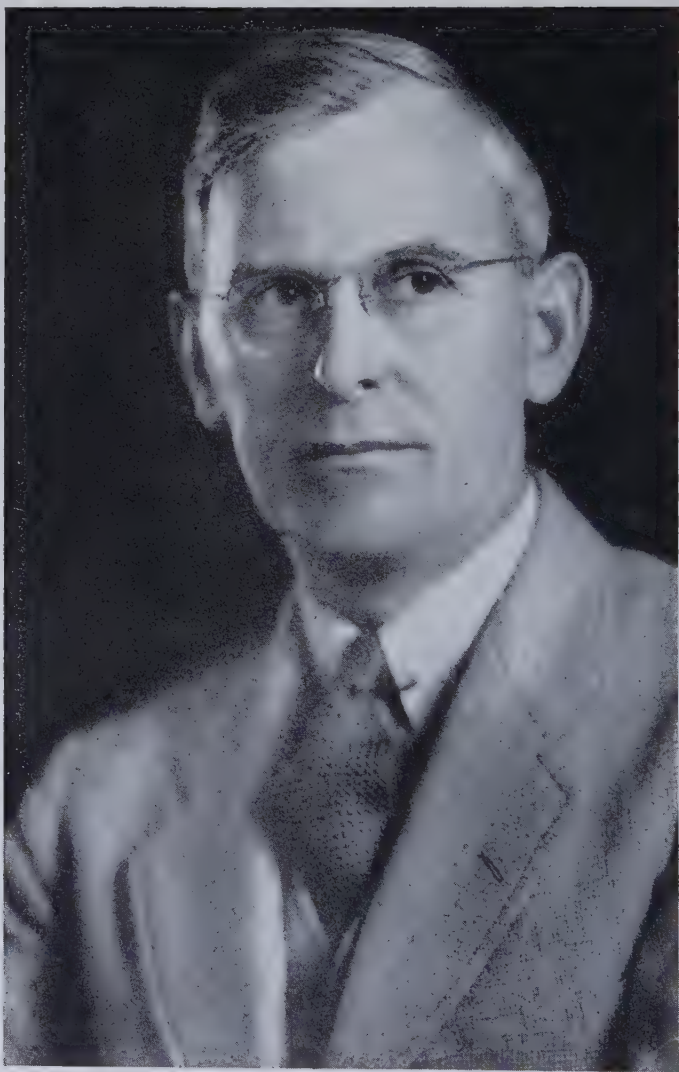
It took considerable persuasion on the part of friends, and in particular his uncle Francis Grace, to induce Terence to continue his education. This Mr. Grace, a mining engineer in New Zealand, had hoped to have his nephew become his geologist when training was completed. However, Mr. Grace died during the last year of Terence's graduate work. It was nearly six years after coming to the United States that Terence entered the University of North Dakota to study mining engineering. He had caught the "fever of America" and realized he did not want to return to England to live. His first course in geology was greatly stimulated by recollections of his childhood days in Sussex along the sea-

coast with its white chalk cliffs and over the rolling downs country farther inland. In three years time he was graduated but stayed on another year, as a Fellow, to finish his master of science degree. From 1913–1915 he was a Fellow at the University of Chicago where he completed the Ph.D. degree in 1915. It was here that his mind turned to the problems of pre-Cambrian geology.

His first field experience was gained while a student at North Dakota; for four summers he was assistant to the state geologist. Four more summers were spent as Geologist on The Geological Survey of Canada; and during the summers of 1919–1931, he was Chief of Survey Party in Canada. In 1915 he accepted an instructorship at the University of Minnesota and was advanced to Assistant Professor in 1917. In 1919 he came to the University of Illinois as Associate Professor and Chairman of the Department of Geology and Geography. He was promoted to Professor in 1925 and continued to serve as Chairman until 1928.

His outstanding contributions to science were in the field of pre-Cambrian geology and included the mapping of numerous large areas in Ontario. The first was his work on the Espanola District of Ontario. This study was one of several conducted in an attempt to correlate certain rocks at Sudbury with those along the north shore of Lake Huron. The demand for iron during World War I led to a study of the Michipicoten iron ranges in which he participated. Some of the results of these studies were published by him in joint authorship with W. H. Collins in 1926. In 1924 and 1926 he published on the Huronian-Grenville relations and showed evidence that some of the so-called Grenville of south-eastern Ontario is to be correlated with the Huronian of the north shore of Lake Huron, and that the associated granite is Killarnean and not Laurentian. In the summers of 1923 and 1926, he studied the rocks north of Killarney, on Georgian Bay; and in 1930 he published, with Collins, the thesis that the "Disappearance of the Huronian" east of Killarney is due largely to granitization or the transformation of Huronian sediments by igneous material. An earlier paper (1927) on the "Killarney Gneiss and Migmatites" deals with the processes involved in this type of transformation. In the French River Area, east of Killarney, he believed the granitic rocks were replacements of sedimentary rocks and that here was an example of how batholithic material might be derived.

Among his early, but relatively minor contributions, were numerous papers on meteorites, structural and tectonic geology, ore deposits and general geology. In 1931 the Canadian Geological Survey was no longer permitted to employ foreign geologists; and it was, therefore, no longer feasible for Doctor Quirke to continue his field studies in this pre-Cambrian area. Unfortunate as this may have been, he turned to consulting



TERENCE THOMAS QUIRKE

1886-1947

work in ore deposits and to laboratory studies in the field of mineralogy and crystallography. The results of these studies are to be found in his more recent publications. At the time of his death he had completed for publication a revised edition of his textbook "Engineering Geology."

Doctor Quirke was a member of many national scientific societies and

fraternities. He was a Fellow of the Geological Society of America, the Mineralogical Society of America, the Society of Economic Geologists, and the American Association for the Advancement of Science. He was a member of the American Institute of Mining and Metallurgical Engineers, the Illinois Academy of Science, Sigma Xi, and Gamma Alpha. His interest in geology and geologists of foreign countries is shown by the fact that as a delegate he took on active part in the deliberations in the meetings of the International Geological Congress held in Brussels in 1922 and in Madrid in 1926. He had also been appointed as an official delegate to the Congress to be held in London in 1948.

As a party chief, he felt a keen sense of responsibility for his men and always made careful plans in organizing for explorations. His unselfishness in assignment of duties and his patience in explaining the work to his assistants left nothing but admiration on the part of these men for their party chief. He was a good camper and packer, carrying a great weight for his size. Though not a person of robust stature, he did possess great physical endurance and was a skillful canoeman, having covered many thousands of miles by canoe during his field studies. He had a passionate love for field work and mapping and was extremely thorough and meticulous. Although many of these fine qualities were inborn, it is logical to assume that some of them were more highly developed as a result of his close association, over a period of many years, with his beloved friend and colleague W. H. Collins.

September 23, 1916, he married Anne Laura McIlraith, a student he had met while at North Dakota, and it was about his home and family of three children that many of his outside interests were centered. For years in his home, symbolic of hospitality, refinement and friendliness, students, faculty and others, friend and stranger alike, have been entertained most graciously. He had a profound interest in nature study and outdoor life which is made apparent in his completed but yet unpublished work called "Exploration and Adventure," a book intended for older boys, on the subject of life in the open. One hobby, somewhat allied to his profession, was his interest in gem stones. These stones he had studied and collected for years and, at the time of his death, was preparing a book on the subject. An extensive research, over a long period of time, on the subject of canoes and small craft was completed in a manuscript of several hundred pages. Another pastime was translating certain German works including "The Laws of Rock Metamorphism" by V. M. Goldschmidt and "Types and Nomenclature of Arder (Vein) Rocks" by P. J. Holmquist.

Doctor Quirke was an Episcopalian and had a fine religious spirit. He was a Rotarian, and his diligent performance as counselor for his

fraternity, Sigma Nu, and as a Boy Scout Leader indicates a great pleasure derived from working with young men and boys. He was an enthusiastic and inspiring teacher and his lectures were well seasoned with stories and anecdotes derived mainly from his wide personal experiences.

During the morning of August 19, 1947, Doctor Quirke had taught scheduled classes in geology, but after lunch, while at home, he began to experience some discomfort and shortly realized that the end was near. The end did come at 4:20 P.M. as a result of coronary occlusion. His passing came as a complete and unexpected shock to his many relatives and friends. He will always be remembered by his students who received his counsel and inspiration; by his fellow scientists who knew him for his field work, his writings and his contributions to pre-Cambrian geology; and by his friends who knew him as a real gentleman, a sympathetic and understanding neighbor, and an individual with the utmost respect for his privileges as a citizen of this country.

He is survived by his wife; two daughters Frances Grace (Mrs. Walter Washburn) of Austin, Texas, and Dorothy Geneva (Mrs. Robert Reedy) of Worcester, Massachusetts; a son Terence, Jr., of Urbana, Illinois; two brothers in South Africa; two brothers and two sisters in England; and a brother in Richmond, Virginia.

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PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA AT OTTAWA, CANADA

C. S. HURLBUT, JR., *Secretary.*

The twenty-eighth annual meeting of the Society was held at the Chateau Laurier, Ottawa, Canada, on December 29–31, 1947. The registration figures show that 165 fellows and members attended. The scientific sessions were held in the afternoon on December 29th and 30th and in the morning of December 31st, at which forty-five papers were presented orally and eleven by title. The annual luncheon of the Society, which was held on December 30th, was attended by 140 fellows, members, and guests. This is not only the largest number who have ever attended an annual luncheon but many others were turned away because of lack of space. Following the luncheon Edward H. Kraus presented the Roebling medal to Paul Niggli of Zürich, Switzerland. Professor Niggli is the seventh recipient of the medal and the second European to receive this award. The retiring President, Martin J. Buerger, addressed the Society on the *Rôle of Temperature in Mineralogy*.

On the following pages are given the reports of the officers for the year 1947 as read before the Council at its meeting on December 28, 1947.

ELECTION OF OFFICERS AND FELLOWS FOR 1948

The secretary reported that 378 ballots were cast in the election of officers for 1948: 253 by members and 125 by fellows of the Society. The officers as nominated by the Council were elected and are:

President: Martin A. Peacock, University of Toronto, Toronto, Canada.

Vice-President: A. Pabst, University of California, Berkeley, California.

Secretary: C. S. Hurlbut, Jr., Harvard University, Cambridge, Massachusetts.

Treasurer: Earl Ingerson, U. S. Geological Survey, Washington, D. C.

Editor: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

Councilor (1948–1951): Clifford Frondel, Harvard University, Cambridge, Massachusetts.

The secretary reports that according to the provisions of the constitution the following have been elected to fellowship:

Julian Devereau Barksdale, University of Washington, Seattle, Washington.

Harold E. Buckley, University of Manchester, Manchester, England.

Felix Chayes, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Theodore Ayrault Dodge, Tucson, Arizona.

Harry von Eckermann, University of Stockholm, Stockholm, Sweden.

Reuben B. Ellestad, Metalloy Corporation, Minneapolis, Minnesota.

Antoine Marc Gaudin, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Eberhardt William Heinrich, University of Michigan, Ann Arbor, Michigan.

Ralph Jerome Holmes, Columbia University, New York, N. Y.

George Clayton Kennedy, Harvard University, Cambridge, Massachusetts.

Charles Edmund Marshall, University of Missouri, Columbia, Missouri.

Edward Wilfrid Nuffield, University of Toronto, Toronto, Canada.

Lincoln Ridler Page, U. S. Geological Survey, Custer, South Dakota.

Percy Dudgeon Quensel, University of Stockholm, Stockholm, Sweden.

Kalervo Rankama, University of Helsinki, Helsinki, Finland.

Richard Atwell Rowland, Shell Oil Company, Houston, Texas.

Ward Conwell Smith, U. S. Geological Survey, San Francisco, California.

Bronson Ferrin Stringham, University of Utah, Salt Lake City, Utah.

Charles Joseph Vitaliano, Indiana University, Bloomington, Indiana.

Elizabeth Armstrong Wood, Bell Telephone Laboratories, Murray Hill, New Jersey.

ACTION BY THE COUNCIL

It was voted by the Council to continue in the future the practice of holding the Annual Meeting at the same time and place as the Annual Meeting of the Geological Society. Therefore, the meeting in 1948 will be held in New York City on November 11-13. Because of this change, it will be necessary that the Secretary have abstracts of papers to be presented at the meeting by *September 1, 1948*. The Council also voted that in the future no papers be accepted for presentation by title only.

REPORT OF THE SECRETARY FOR 1947

MEMBERSHIP STATISTICS

To the Council of the Mineralogical Society of America:

	1946	1947	Gain	Loss
Correspondents	6	6	0	0
Fellows	237	254	20	3
Members	625	677	205	153
Subscribers	535	501	115	149
	<hr/> 1403	<hr/> 1438	<hr/> 340	<hr/> 305

The above figures show a net gain of 17 fellows and 52 members and a net loss of 34 subscribers. Considering fellows, members and subscribers together, this shows a total gain of 35. The loss in subscribers over 1946 was due to the cancellation of 95 Russian subscriptions in March of 1947. Although the number of subscribers has been substantially reduced, the number of subscriptions in the Soviet Union has not been reduced a comparable amount, for several institutions are now receiving more than one copy of *The American Mineralogist* and one as many as 25 copies.

The Society lost through death three fellows in 1947: Gregori Aminoff, Joseph P. Connolly, and Terence T. Quirke.

Respectfully submitted.

C. S. HURLBUT, JR., *Secretary*

REPORT OF THE EDITOR FOR 1947

To the Council of The Mineralogical Society of America:

In making an overall report on, and appraisal of, the publication activities of the Society for the current year, two related items should be included: (1) the bimonthly publication, the *Journal*, and (2) the decennial index for the years 1936-1945. The latter, a 200-page author-subject index, is now available for distribution and represents a carefully prepared and complete table of references for volumes 21-30. For the completion of this valuable and indispensable reference volume we are indebted to Drs. Ingerson and Fleischer who have labored long and faithfully in its preparation. An edition of 1300 copies has been printed and this number should be sufficient to meet both the present and future demands. The index is being offered for sale at a price of \$2.00 to members and subscribers, and \$3.00 to non-members.

The *Journal* has likewise experienced a very satisfactory year. The current volume of slightly over 700 pages represents an increase of 100 pages over the previous year. If to the

700 pages we add the 200 pages represented by the decennial index, the over-all total exceeds 900 printed pages which the Society has made available this year to those interested in our science. This grand total of 900 printed pages has been equalled but once and exceeded on only one other occasion in the entire history of the Society.

This increased volume of printing, together with rising costs of labor and materials, is naturally reflected in marked increased printing expenditures. However, this tendency of ascending prices seems to be the order of the day and is not restricted to any one locality or printer. We have enjoyed over a long period of years very efficient service, promptness of publication combined with the use of an excellent quality of coated paper making possible a clarity of reproduction of graphs, diagrams, and photographs that has been the envy of other publications and a "joy to see," as recently expressed in a personal communication from a colleague in an English University. I hope no action will be taken, under the guise of economy, that might in any way retard efficiency or cheapen the character of the Journal through a change in the quality of materials now being used.

The Geological Society has continued its generous financial support for defraying a substantial portion of the publication costs. This past year this aid amounted to \$3000 with an additional appropriation of \$500 for the cost of colored plates if and when such illustrations were deemed necessary or highly desirable. Likewise, some additional financial assistance was received from the Geological Society for the printing of the decennial index. Recognition and deep appreciation is here expressed for this generous and timely assistance, by virtue of which it was possible to include two articles requiring colored insertions.

There has been no back log of accumulated manuscripts under our present bimonthly system. If the Journal had appeared monthly this past year, the total number of pages would have been exactly the same; only each issue would have been half the size while a substantial increase in the over-all cost for the volume would have resulted. The cost of covers, for binding and for mailing would have been doubled, and there would have been a further percentage increase resulting from the doubling up of change-overs in the typesetting department, press room, and folding division. Aside from the additional cost involved in a change-over to a monthly magazine, printing difficulties would arise, as the new typesetting equipment that has been on order for some time has not yet been delivered. Therefore, considered from all angles it would seem necessary, at least for the present, to continue as a bimonthly, since all material thus far received has been adequately taken care of without undue delay and at a minimum cost.

In a detailed analysis of the Journal for 1947, we find that volume 32 contains 702 pages, exclusive of index. Leading articles, which number 57, occupy 79.3% of the total space. Table 1, which accompanies this report, indicates the distribution of the leading articles in the various fields listed. It might be of some interest to note that the average length of each of the main articles was slightly less than 10 printed pages.

If to the 57 leading articles we add 20 shorter papers appearing under the heading of "Notes and News," we obtain a total of 77 published manuscripts for the calendar year. These contributions were obtained from 83 contributors associated with 48 different universities, research bureaus, and technical laboratories.

The Journal for 1947 carries detailed descriptions of five new minerals: paraschoepite, epianthinite, fairchildite, buetschliite, and groutite. Two hundred and sixty-seven illustrations of various types assist in clarifying the descriptive portions of the text.

In one respect, at least, volume 32 is quite unique, namely, in the number of papers submitted and printed from contributors residing outside of the States. Sixteen such manuscripts were received representing the following 11 countries: Australia, Belgium, Canada, England, Finland, Germany, Italy, Japan, New Zealand, Norway, and South Africa.

The accompanying Table 1 summarizes in detail the distribution of subject matter in volume 32.

TABLE 1. DISTRIBUTION OF SUBJECT MATTER IN VOL. 32

<i>Subjects</i>	<i>Articles</i>	<i>Pages</i>	<i>Per Cent of Total</i>
Leading articles*			
Descriptive Mineralogy	9		
Chemical Mineralogy	17		
Structural Mineralogy	12		
Geometrical Mineralogy	1		
Petrography	8		
Optical Mineralogy	4		
Mineralography	1		
Memorials	5		
Miscellaneous			
	57	557	79.3
Shorter articles	20	33½	20.7
Notes and news	19	8	
Proceedings of societies	11	78½	
Book reviews	11	14	
New mineral names	35	11	
Total entries	153	702	100.0
Illustrations	267		
Index, Title page, Table of contents		16	
Grand total		718	

* Leading articles average 9.8 printed pages each.

Respectfully submitted

WALTER F. HUNT, *Editor*

REPORT OF THE TREASURER FOR 1947

To the Council of the Mineralogical Society of America:

Your treasurer submits herewith his annual report for the year beginning December 1, 1946, and ending November 30, 1947.

RECEIPTS

Cash on hand December 1, 1947	\$ 7,392.92
Dues and subscriptions	4,289.31
Sale of back numbers	878.26
Authors' charges on separates	549.16
Interest and dividends from endowment	3,139.95
Payments on principal of Trenton Mortgage stock	273.11
Geological Society of America aid for printing the Journal	4,059.77
Geological Society of America aid for printing new Index	1,000.00
Advertising	209.89
Sale of 20-volume Index	2.00
Sale of Index to volumes 21-30	53.00
	<hr/>
	\$21,847.27

DISBURSEMENTS

Printing and distribution of the Journal (6 issues)	\$ 7,225.76
Reprinting two out-of-print issues	918.50
Printing and distribution of separates	740.34
To the Editor, Secretary, and Treasurer	1,250.00
Postage	123.09
Clerical help	434.25
Office equipment	60.98
Printing and stationery	215.55
Safety deposit box	9.60
Telephone and telegraph	8.75
Committee expenses	17.37
Society luncheon (1946)	4.94
Roebling Medal	132.34
Exchange charges on checks75
Returned check	3.60
Refund of dues	3.00
Travel expenses of Editor and Secretary to Annual Meeting	111.55
Preparation of Index to volumes 21-30	1,353.50
Printing of Index to volumes 21-30	2,035.93
New securities purchased	5,050.00
Commission on new securities	13.50
Accrued interest on bonds purchased	81.95
Program and abstracts (1946)	265.85
Back numbers of the Journal purchased	38.00
	<hr/>
	\$20,095.10
Cash balance November 30, 1947	1,752.17
	<hr/>
	\$21,847.27

The endowment funds of the Society as of November 30, 1947, consist of the following securities:

BONDS

5M U. S. Treasury, 2½%	\$ 5,190.63
5M Illinois Central, 4%	3,887.50
5M Southern Railway, 5%	5,743.75
5M Cleveland Union Terminal, 5%	5,068.75
6M Atlantic Coast Line, 4½%	5,257.50
5M New York Central, 5%	4,300.00
4C Great Northern, 5½%	400.00

PREFERRED STOCKS

50 shares, Virginia Electric & Power Co., 5%	\$ 5,942.50
55 shares, U. S. Steel, 7%	6,946.20
50 shares, Union Pacific, 4%	4,570.25
60 shares, Jones and Laughlin, A, 5%	4,987.50
10 shares, Consolidated Edison	1,066.64
5 shares, Public Service of New Jersey	702.00
37 514/1000 shares, Trenton Mortgage Service	1,481.37*

COMMON STOCKS

50 shares, Chesapeake and Ohio Railway.....	\$ 2,368.75
50 shares, Pennsylvania Railroad.....	1,468.75
25 shares, Standard Oil of New Jersey.....	1,356.25
30 shares, American Telephone and Telegraph.....	4,119.32
1 share, New York, Chicago & St. Louis Railroad.....	37.00
	<hr/>
	\$64,894.66

Respectfully submitted,

EARL INGERSON, *Treasurer*

* Residual value.

DANA FUND

Disbursements are made to needy mineralogists in war areas, and to needy families of deceased mineralogists in war areas.

RECEIPTS

Available balance, November 30, 1946.....	\$615.73
Interest.....	5.52
	<hr/>
	\$621.26

DISBURSEMENTS

Disbursed.....	\$150.00
Available balance, November 30, 1947.....	\$471.25
	<hr/>
	\$621.25

Respectfully submitted,

EARL INGERSON, *Treasurer*

REPORT OF THE AUDITING COMMITTEE

To the President of the Mineralogical Society of America:

The Auditing Committee has examined and verified the accounts of the Treasurer of the Mineralogical Society of America for the fiscal year ending November 30, 1947. The securities listed in the Treasurer's report, with all future coupons on the coupon bonds attached, are in the safety deposit box at the Friendship Branch of the Riggs National Bank of Washington, D. C.

Respectfully submitted,

STERLING B. HENDRICKS

K. J. MURATA

ALTON GABRIEL, *Chairman*

ABSTRACTS OF PAPERS PRESENTED AT THE TWENTY-
EIGHTH ANNUAL MEETING OF THE MINERALOGICAL
SOCIETY OF AMERICA, OTTAWA, CANADA,
DECEMBER 29-31, 1947

UNIQUE ASSOCIATION OF THALLIUM AND RUBIDIUM IN MINERALS

L. H. AHRENS

Massachusetts Institute of Technology, Cambridge, Massachusetts

Spectrochemical analyses of various minerals have shown that "alkali metal" thallium and rubidium are found only in potassium minerals and the cesium mineral pollucite, and that in these minerals the Tl:Rb association is very close. Altogether 167 specimens have been analyzed quantitatively, the selection comprising lepidolite, amazonite, hydrothermal pegmatitic microcline, primary pegmatitic microcline, zinnwaldite, biotite, muscovite, phlogopite, pollucite, rhodizite, and cesium beryl. The mean weight ratio $\%Rb_2O/\%Tl_2O$ was determined as 100, and the vast majority of the ratios fall within the limits of 35-300; the extreme limits are 10 and 650. A plot of $\log \%Rb_2O$ vs. $\log \%Tl_2O$ produced a curve of unit slope over the thousand fold range of concentration that could be investigated. There appears thus to be no shift in the ratio Rb/Tl throughout the selective crystallization of minerals and the ratio seems to be independent of the type of host mineral: the ratio does, however, vary to some extent from area to area, and it seems likely that the cause for this variation is a chemical one. The reasons for the close association of "alkali metal" thallium and rubidium are that the radii of their ions are identical and that in certain pertinent respects, their chemical properties are very similar.

With the possible exception of the pair Zr:Hf, which elements are very closely associated in minerals, "alkali metal" thallium and rubidium are perhaps the most closely associated pair of elements in the earth's crust, and their association is made more unique because thallium is a Group 3b element, whereas rubidium is an alkali metal (Group 1a).

The abundance of thallium in the earth's crust has been estimated as 0.0003% Tl, by weight.

WEATHERING OF PLAGIOCLASE FELDSPARS TO BAUXITE*

VICTOR T. ALLEN

Institute of Geophysical Technology, Saint Louis University, Saint Louis, Missouri

In Oregon plagioclase feldspars weathered to kaolinite-halloysite or to beidellite-nontronite; then, gibbsite and bauxite formed from these clay minerals by the removal of silica. Contrary statements in four recent publications subordinate this two-stage process: "that calcium feldspar gives free aluminum hydroxide," "that gibbsite precedes kaolin in the weathering of all but the most silicic igneous rocks," "that under tropical conditions laterite is developed from basic igneous rocks and clay from granitic rocks," and "that kaolinite is an insoluble hydrated silicate and the change ends with its formation."

A hole drilled by Alcoa into one Oregon ferruginous bauxite deposit indicates that weathering penetrated downward more than 175 feet with alumina, iron, titanium, and water increasing progressively but not regularly at the expense of silica. Alumina ranges from 47-25 per cent in the upper 50 feet to 35-24 in the underlying 100 feet, ferric oxide from 49-18 per cent to 32-15, titania from 8-3 per cent to 7-3, water from 25-13 per cent

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to 13-9, and silica increases from 2-23 per cent to 21-26. A transitional layer of clay over 100 feet thick separates the bauxite at the top of the profile of weathering from the underlying parent basaltic materials of Miocene age. Irregularities within the weathered zone reflect original differences in chemical composition. Detrital sands and basaltic lava with a glassy groundmass that weathered easily to nontronite provided zones of increased permeability and susceptibility to alteration; differentiation of the basaltic lavas caused notable differences in the original silica and titania of certain horizons.

INFRA-RED LIGHT FOR MINERAL DETERMINATION

RENÉ BAILLY

Washington University, Saint Louis, Missouri

Many minerals which are opaque in visible light are transparent in the infra-red. By substituting a photo-electric ocular, sensitive in the infra-red, for the ordinary eye-piece, it is possible to study their optical properties just as for nonopaque minerals. Oriented thin sections can be studied with the polarizing microscope. By means of the universal stage, the optical characters, including optic sign, birefringence, axial angle, etc., can be determined. Photography with infra-red sensitive plates is useful.

The best method for determining the refractive index generally is the prism method with normal incidence. The indices of many opaque minerals are too high to be determined with the total reflection refractometer. An adjustable slit before the photo-cell takes the place of the cross-hair in the visual eyepiece of the goniometer's telescope. In many cases, the photo-electrical method is more precise than the visual one. The photo-electric current is very variable, according to the character of minerals. It is hardly possible to use a galvanometer without previous current amplification. The amplifier must be very sensitive and stable. The infra-red light (8,000-10,000 Å) is produced by a filament bulb or metallic arc lamp with adequate filters.

The properties of the following minerals have been determined: molybdenite, stibnite, bournonite, stephanite, enargite, tetrahedrite, tennantite, ferberite, wolframite, hübnerite, chromite, hematite, goethite, hauerite, thoreaulite, sphalerite. The variation of index with the chemical composition has been studied for several species. The correlation is especially good for wolframite. Curves are presented showing the dispersion of hübnerite, hematite, goethite, thoreaulite, sphalerite, calcite, up to 10,000 Å.

METAMORPHIC ROCKS OF THE LOWER METHOW VALLEY, WASHINGTON

JULIAN D. BARKSDALE

University of Washington, Seattle, Washington

A series of paragneisses composed of hornblende-chlorite-epidote-albite schist, hornblende schist, biotite-hornblende-quartz-feldspar gneiss, biotite quartzite, and calcite-epidote-garnet-rock was intruded by a remarkably uniform granitic rock now cataclastically metamorphosed to a distinctive biotite granite gneiss. The gneissic structure of the latter parallels that of the paragneiss near their mutual contacts. The metamorphic rocks outcrop over an area of approximately 125 square miles in the lower reaches of the Methow Valley. Migmatites formed from the paragneisses by the intrusion of hornblende granodiorite and quartz monzonite of the Chelan batholith extend south and west from the Methow along the Columbia River to the vicinity of Lake Chelan. In contrast the granitic rocks of the Okanogan batholithic complex invade the metamorphic rocks with but minor contact effects.

DISTRIBUTION OF OXYGEN IN THE LITHOSPHERE

TOM. F. W. BARTH

University of Chicago, Chicago, Illinois

Oxygen, which makes up more than 90 per cent by volume of the total lithosphere, shows the highest concentration in the outer shell. The regular decrease with depth represents an approximation to thermodynamic equilibrium. When highly oxidized surface rocks are brought down to great depths, oxygen will be squeezed out of the mineral lattices and returned to the surface. Therefore the deeper parts of our globe are not able to become oxidized.

TYROLITE, HIGGINSITE AND CORNWALLITE

L. G. BERRY

Queen's University, Kingston, Ontario

X-ray and optical studies on numerous specimens of hydrated basic copper arsenates yield the following data:

Tyrolite: orthorhombic; probable space group $Pmma$; the unit cell with $a=10.50$, $b=54.71$, $c=5.59$ Å, $a:b:c=0.1919:1:0.1022$, contains $4[Cu_2Ca_2(AsO_4)_4(OH)_{10} \cdot 10H_2O]$. Specific gravity, measured 3.27 (Hillebrand); calculated, 3.27. Optical characters; biaxial, negative, $X=b$, optic plane $\parallel (001)$. Crystals from Schwartz, Tyrol, are lath-like and elongated $\parallel a$; they contain microscopic spherical inclusions with a radiating structure. Crystals from Centennial Eureka Mine, Tintic, Utah, are elongated $\parallel c$. The unit cell dimensions, $a=10.34$, $b=26.9$, $c=5.57$ Å, given by Wolfe for "trichalcite" from Turginsk, suggest probable identity of "trichalcite" with tyrolite.

Higginsite: several specimens labelled "conichalcite" and "erinite" from Utah, Nevada, and Cornwall give identical x-ray powder patterns which prove to be identical with the pattern of higginsite from Bisbee, Arizona. A crystal of "erinite" from Utah is orthorhombic with probable space group $Pnam$ and unit cell, $a=7.40$, $b=9.26$, $c=5.87$ Å. These elements agree well with the elements for higginsite given by Strunz (1939) and Richmond (1940).

Cornwallite: the identical x-ray powder patterns given by cornwallite from Cornwall and several specimens of "erinite" from Utah indicate probable isomorphous relationship of this mineral with pseudomalachite. The name cornwallite is retained for this mineral.

THE SYSTEM $MgO-SiO_2-H_2O$

N. L. BOWEN AND O. F. TUTTLE

Geophysical Laboratory, Washington, D. C.

The system has been investigated up to 900°C. and 30,000 lbs./in.² Four-phase P-T curves have been determined showing equilibrium relations between the vapor (or fluid) phase and the crystalline phases serpentine, talc, forsterite, enstatite, and silica. No liquid phase has been encountered, a fact that is suggestive in connection with the problem of the existence of "serpentine magma" in the pressure-temperature range investigated.

ROLE OF TEMPERATURE IN MINERALOGY

M. J. BUERGER

Massachusetts Institute of Technology, Cambridge, Massachusetts

Temperature endows a mineral with energy beyond that of its static crystal structure. This excess energy is the cause of many well-known mineralogical relationships, which can be comprehended as transformations.

Three different structural changes may occur in the transformation of one crystalline

phase to another (polymorphism). High-low transformations may be called *displacive* from a structural viewpoint since they correspond with slight displacements of the atoms. Forms connected by displacive transformations always have related symmetries, the high-temperature form having the higher symmetry. Sluggish transformations may be called *reconstructive* since they correspond structurally to destruction of one structure and construction of a new structure from the same units. Gradual transitions correspond structurally with disordering of the atoms in the structure. Forms connected by gradual transition also have related symmetries. The disorder is the cause of solid solution. Falling temperature requires an ordering transition. If the crystal which must become ordered is a solid solution, it is necessary for one phase to transform into two; in other words, the transition causes unmixing. Many common minerals, for example, chalcopyrite and feldspar, have hitherto unrecognized high-temperature forms due to a disorder transition.

Another kind of transformation develops when an energy increase can disrupt *part* of the structural unit. When the character of the structure permits this, a reaction series results. Thus, Bowen's reaction series is merely a series of increasingly fragmented silicate units.

When a wave of temperature energy reaches the surface of a crystal, it is in a position to snap off surface units provided that the energy exceeds the bonding energy of the units. This temperature corresponds with the critical temperature of recrystallization, and the surface transformation provides the mechanism of metamorphism.

A PETROGRAPHIC REFRACTIVE INDEX METHOD

NELSON B. DODGE

Bausch and Lomb Optical Co., Rochester, New York

With dark-field illumination, color criteria provide an alternative to the usual methods for comparing index of crushed grains with immersion media. Since organic immersion liquids have steeper dispersion curves than inorganic solids, spectrum colors are produced from white light by refraction at interfaces of grains and liquid. With ordinary illumination when the dispersion curves intersect in the yellow, the oblique illumination test produces colored grain borders as explained by F. E. Wright and others. Dark-field colors appear in bright contrast to a dark background, affect grains everywhere in the microscope field, and require no changing of focus.

Most microscopes can be adapted for dark-field illumination, which requires a hollow cone of light from the condenser, focused on the preparation, having a greater aperture than the objective. The field of view is dark, except where refraction and reflection in the preparation send light to the eye. When solid and liquid indices differ widely, grains appear white against a dark background. When indices differ by a few units in the second decimal place, or less, grains are yellow if higher and blue if lower in index than liquid. At equality of sodium index, $\pm .001$, grains appear purplish blue with a scattering of deep red borders.

The colors can be explained as a result of the Christiansen effect. They are due to the subtraction of the lost transmitted wavelengths from white light.

KLOCKMANNITE AND ARTIFICIAL CuSe

J. W. EARLEY

University of Toronto, Toronto, Canada

In the course of a study of natural and artificial copper selenides now in progress, the compound CuSe was prepared by dry fusion and by hydrosynthesis, and the crystalline products were found to be physically and structurally identical with klockmannite from Sierra de Umango, Argentina. The pyrosynthetic material has the specific gravity 5.99.

The minute greenish black hexagonal plates of hydrosynthetic CuSe show $c(0001)$ (perfect cleavage), $n(10\bar{1}2)$, $r(10\bar{1}1)$, $m(10\bar{1}0)$, and the unit cell with space-group $C6/mmc$, $a=3.93$, $c=17.22$ kX, contains $6[\text{CuSe}]$, and has the calculated density 6.12. A superstructure has $a'=12a$. Klockmannite is clearly isostructural with covellite.

LOUGHLINITE, A NEW HYDROUS MAGNESIUM SILICATE*

JOSEPH J. FAHEY WITH X-RAY ANALYSIS BY JOSEPH M. AXELROD
U. S. Geological Survey, Washington, D. C.

The name loughlinite, in honor of the late Dr. Gerald F. Loughlin, former Chief Geologist of the United States Geological Survey, is given to a new mineral from the Green River formation of southwestern Wyoming.

This mineral was first found in 1940 in the drill core of the John Hay, Jr., Well No. 1, and again in 1946 in the drill core of the Union Pacific Well No. 4, both in quantities too small for adequate investigative work. In the summer of 1947 many excellent samples were obtained from material excavated during the sinking of the shaft of the Westvaco Chlorine Products Corporation, drilled for the purpose of mining trona. These three locations are between eighteen and twenty miles west of Green River, Sweetwater County, Wyoming.

Loughlinite occurs in veins in low-grade oil shale that contains crystals of shortite. It has an asbestos-like appearance, a silica-magnesia ratio of two to one, and gives an x-ray powder picture unlike any known magnesium silicate.

* Published by permission of the Director, U. S. Geological Survey, Department of the Interior.

OBSERVATIONS ON WEBERITE AND JARLITE

R. B. FERGUSON

University of Manitoba, Winnipeg, Canada

Fragments of weberite, oriented optically, gave the unit cell with space-group $Ibmm$ or $Ibm2$, $a=7.30$, $b=7.05$, $c=9.97$ kX, containing $4[\text{Na}_2\text{MgAlF}_7]$; $X=a$, $Y=b$. Poor crystals of jarlite (sp. grav. 3.87), also oriented optically, gave the unit cell with space-group $C2/m$ or $C2$ or Cm , $a=15.99$, $b=10.82$, $c=7.24$ kX, $\beta=101^\circ 49'$; $Y=b$, $Z:c=+84^\circ \pm 2^\circ$; $\alpha=1.430$, $\beta=1.435$, $\gamma=1.437$, $2V=90^\circ \pm 10^\circ$. "Meta-jarlite" (sp. grav. 3.65, with inclusions) gave $\alpha=1.429$, $\beta=1.431$, $\gamma=1.434$, and an x-ray powder pattern hardly distinguishable from that of jarlite. Sharp powder photographs of ralstonite show indications of non-cubic symmetry, and the yellow ochre "hagemannite" is mainly ralstonite rather than thomsenolite. These results were found to confirm and add to published results by C. Brosset (Diss. Stockholm, 1942—M.A. 10-16).

AQUEOUS EMANATION FROM PARÍCUTIN VOLCANO

W. F. FOSHAG

U. S. National Museum, Washington, D. C.

Large quantities of water vapor are emitted from the crater of Parícutin volcano. An estimate based on observations on May 27, 1945, gives 16,000 tons per day, compared to 100,000 tons of lava emitted. The characteristics of the vapors emitted from the crater vent differ from those emitted directly from the lava vents, suggesting considerable dilution of magmatic emanations by groundwaters. It is suggested the rock alteration in many ore deposits is due in part to activated groundwaters.

USEFUL ASPECTS OF THE FLUORESCENCE OF ACCESSORY-MINERAL ZIRCON

WILFRID R. FOSTER

Champion Spark Plug Company, Ceramic Division, Detroit, Michigan

The mineral zircon has long been known to exhibit fluorescence when exposed to ultra-violet radiation. Hitherto little practical use appears to have been made of this phenomenon. Its application is here recommended in the inspection of commercial concentrates of zircon, and of other minerals containing zircon as an impurity. Comparison of the fluorescent behavior of grains of zircon from igneous rocks of different ages, and from igneous as compared to sedimentary sources, reveals certain contrasts. The possible usefulness of such contrasts in the solution of a number of petrological problems is discussed. Reference is also made to the fluorescence of accessory-mineral apatite, and of certain other minerals found in association with zircon.

ENGINEERING GEOLOGIC STUDIES OF THE UPPER MISSOURI RIVER BASIN

PORTLAND P. FOX

Bureau of Reclamation, Billings, Montana

Extensive geologic studies and foundation explorations have been conducted by the Bureau of Reclamation on twenty dam sites on the upper Missouri River and tributaries during the past three years. A wide variety of foundation problems have been encountered at these sites and the need and value of a complete geologic investigation and interpretation has been demonstrated at each dam site. Approximately half of the twenty dam sites are located in the Northern Great Plains on soft to semi-hard, unconsolidated, compacted Upper Cretaceous and Tertiary sediments. In addition to the low compressive and shear strengths of the unconsolidated sediments, they contain numerous interbedded layers of bentonite and bentonitic-like clays.

The dam sites located on the Paleozoic and pre-Cambrian rocks on the east slopes of the northern and middle Rocky Mountains generally present less serious foundation problems, but wide zones of fault gouge and limestone cavities are common problems.

The proposed construction of numerous large dams on the upper Missouri River and tributaries on unconsolidated sediments present many difficult foundation, design, and construction problems.

A SECOND OCCURRENCE OF BRAZILIANITE*

CLIFFORD FRONDEL AND MARIE LOUISE LINDBERG

Harvard University and U. S. Geological Survey

A second occurrence is recorded for brazilianite, at the Palermo mine, near North Groton, Grafton Co., New Hampshire. The mineral occurs as a late hydrothermal product in a granite pegmatite of the quartz-core type, in the following association and sequence:

quartz—brazilianite—apatite—whitlockite—quartz (last).

The crystallographic, optical and physical properties conform closely to those of the Brazilian crystals. Observed forms: $a\{100\}$, $b\{010\}$, $n\{011\}$, $o\{111\}$, $g\{\bar{1}11\}$, $s\{211\}$, $x\{101\}$, $v\{301\}$, $q\{\bar{1}21\}$. The crystals have an elongate, four-sided appearance due to the relatively large development of $n\{011\}$ and $g\{\bar{1}11\}$ and the near suppression of the prism zone. The crystals range in size up to about three-fourths inch along $[100]$. Color chartreuse-yellow. Specific gravity $2.985 \pm .005$. Optically positive, n (Na): $X=1.602$, $Y=b=1.609$,

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$Z=1.623$, $X \wedge c = -20^\circ$, $2V=71^\circ$ (calc.); dispersion $r < v$, faint. A redetermination of the gravity and refractive indices for the Brazilian crystals gave $G=2.980 \pm .005$; $X=1.601$ $Y=1.608$, $Z=1.620$. A chemical analysis of the Palermo crystals (by M.L.L.) gave: Na_2O 8.29, K_2O 0.20, Al_2O_3 42.85, Fe_2O_3 0.03, TiO_2 0.05, P_2O_5 38.79, $\text{H}_2\text{O}-$ 0.04, $\text{H}_2\text{O}+$ 9.91, total 100.16. The analysis conforms closely to the established formula, $\text{NaAl}_3(\text{PO}_4)_2 \cdot (\text{OH})_8$.

ISOMORPHIC PHENOMENA IN THE MELILITES

JULIAN R. GOLDSMITH

University of Chicago, Chicago, Illinois

Experimental determinations have shown that $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ forms a partial solid solution series with $\text{Ca}_2\text{Al}_2\text{SiO}_7$ (artificial gehlenite). A substitution of Al for Ca is here involved, which was hitherto unknown in silicates and has been considered unlikely because of the rather large size difference of the two ions.

The soda content of melilites was also investigated, it being found that 15 per cent of the hypothetical "molecule" $\text{Na}_2\text{Si}_3\text{O}_7$ can be taken into solid solution with gehlenite. There is no solid solution of this soda member with akermanite ($\text{Ca}_2\text{MgSi}_2\text{O}_7$); thus the artificial melilites contain less than 15 per cent $\text{Na}_2\text{Si}_3\text{O}_7$, the absolute amount decreasing with an increase in the akermanite content of the mix crystals. The fact that some published analyses of natural melilites show more soda (up to 5.44% Na_2O) than can be accounted for by the determined maximum of 15 per cent $\text{Na}_2\text{Si}_3\text{O}_7$ (3.85% Na_2O) would indicate that more careful work on natural melilites should be done.

A PART OF THE SYSTEM $\text{H}_2\text{O}-\text{H}_3\text{PO}_4-\text{AlPO}_4$

JOHN W. GRUNER

University of Minnesota, Minneapolis, Minnesota

This work is being done in connection with the growing of crystals of AlPO_4 and is sponsored by the Squier Signal Laboratories, U. S. Signal Corps, Fort Monmouth, N. J. Only the part of the system is being investigated which contains only solution at room temperature. Crystals form in these solutions on raising the temperatures. Hydrates of AlPO_4 have been found to about 140°C . depending upon concentrations. Above this temperature anhydrous αAlPO_4 (berlinite) crystallizes. The pressures accompanying each concentration at given temperatures are also being measured. Anhydrous AlPO_4 grown under these conditions has an inversion point from α to β within 5°C . of that of quartz (573°C .). It also resembles quartz very closely in many other respects.

SOME ASPECTS OF REGIONAL METAMORPHISM IN NORTHERN MANITOBA

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Argillite, greywacke, arkose, and basic volcanic rocks of the Snow group in northern Manitoba grade into Kiseynew schists and gneisses. Isograds of regional metamorphism trend east-west and intensity of metamorphism increases from south to north. However, the isograds in arenaceous and volcanic rocks occur at a more northerly latitude than those in argillaceous members. Consequently it is inferred that these finer grained rocks are more sensitive to effects of regional metamorphism than are the coarser grained varieties, and this sensitivity persists to rocks of the highest grades of metamorphism. The zones of regional metamorphism characterized by the presence of staurolite and sillimanite are well developed in sedimentary rocks of appropriate composition and grade into one another, but no kyanite was found anywhere in the area studied. It is concluded that the staurolite zone

extends into the zone normally distinguished by kyanite. Explanations are sought for the lag in degree of regional metamorphism of arenaceous and volcanic rocks as compared with fine-grained sedimentary rocks, and for the lack of diagnostic kyanite.

PSEUDO-EXSOLUTION INTERGROWTHS DUE TO PERITECTIC REACTIONS INVOLVING PARTIAL DISSOCIATION

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In a partial study of the NiAs-NiSb system, experimental results show that these substances form a complete solid solution series after fusion in vacuo. On heating, however, NiAs partially breaks down above 850°C. and slowly at 500°C to form Ni₃As₂ (artificial maucherite) according to the peritectic reaction as noted by Friedrich:



On addition of antimony to the nickel arsenide lattice, the structure is stabilized and this dissociation does not occur to any marked extent when between thirty and forty atomic percent of NiSb is present.

Intergrowths produced from both artificial and natural niccolite consist of both a blade and a net type resembling textures usually ascribed to unmixing of solid solutions. A very similar natural net type of intergrowth of niccolite and maucherite found in a specimen of ore from the Studbury district, Ontario, is hence interpreted as due to a partial dissociation of niccolite. The dissociation is due either to a post-niccolite heat effect, or to a reduction of confining pressures while high temperatures still prevailed. Although the reaction involves a rearrangement of Ni and As atoms to form the lattice of "maucherite," and since the original pure niccolite is in no sense a solid solution the prefix is necessary in describing the resulting intergrowths as a pseudo-exsolution type.

Work on artificial pyrrhotite-pentlandite intergrowths suggests that at least some of these may be similarly related to a peritectic reaction involving the partial loss of sulphur from nickeliferous pyrrhotite solid solutions. However, since the original host is a solid solution and migration of nickel atoms to the pentlandite segregations occurs during heating, the resulting intergrowths must be regarded as true exsolution effects.

PEGMATITES OF THE EIGHT MILE PARK AREA, COLORADO

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The Eight Mile Park area, just west of Canon City in Fremont County, Colorado, is a plateau of 30 square miles roughly bisected by the Royal Gorge of the Arkansas River. The underlying rocks consist of three units whose contacts strike northeast-southwest. The northwestern batholith of Pikes Peak granite is separated by a narrow belt of Idaho springs schists from the southeastern body of injection gneiss. Large pegmatite bodies, many of which have been mined for feldspar and mica, occur in both the granite and the schists along the batholith margins. Those bodies in the granite are flat-lying sheet-like masses that transect the granitic flow structure. Those in the schist are moderately to steeply dipping sills along the metamorphic foliation. The latter are characterized by a well-developed zonal structure consisting of border, wall, intermediate, and central zones. Hydrothermal replacement units, which are also strongly developed in this type of body, characteristically lie along the footwall contacts between central and intermediate zones, and replace parts of both. The sheet-like bodies are marked by less definite zoning and weakly developed hydrothermal units. The total number of mineral species found is 35. Among the rarer species, which occur only in the replacement units, are fremontite (the type locality), and beyerite.

THE TURRET CORUNDUM DEPOSITS, CHAFFEE COUNTY, COLORADO

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The corundum deposits near Turret, in Chaffee County, Colorado, have been known since about 1890. The best known occurrences are near the abandoned Calumet Iron mine in a thin horizon of sillimanite- and graphite-bearing schist of Pennsylvanian age, which lies near the contact between garnet-bearing marble (metamorphosed Leadville limestone) and a mafic igneous rock. The corundum crystals, some of which attain a diameter of $\frac{1}{4}$ inch, are deep blue in color. A few contain fracture-free parts.

In a less well-known deposit, which is just south of Turret, corundum is disseminated throughout the central part of a 50-foot zone of chlorite rock that lies within pre-Cambrian muscovite-garnet and quartz-biotite schists. Much of the coarse chlorite occurs in veins and appears to be hydrothermal in origin. At the southeast end of the deposit a marked zonal structure is developed by the alternation of coarse chlorite layers with layers of garnet and actinolite rock. Other minerals are: quartz, plagioclase, biotite, anthophyllite, hoegbomite, spinel, and magnetite.

It is noteworthy that in the first deposit corundum occurs as thin basal plates whereas in the second the grayish blue crystals are barrel-shaped, tapering prisms.

OPTICAL PROPERTY CURVES FOR COMMON CLINOPYROXENES

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An improved set of optical property curves for common rock-forming clinopyroxenes has been prepared. The basis for drawing the curves was furnished by 35 new analyses, and from data taken from the work of Bowen, Schairer and others on synthetic end members of the series. A large portion of the clinopyroxene field is poorly represented or not represented at all in the available data so that further revision of the curves will be necessary as specimens to fill the gaps in the present data become available.

The effect of Al_2O_3 , Fe_2O_3 , Cr_2O_3 , MnO , and TiO_2 on optical properties is discussed as well as the effect of exsolution of lamellae of orthopyroxene.

The chemical analyses were financed by a grant from the Geological Society of America and by Princeton University.

MULTIPLE DIFFERENTIAL THERMAL ANALYSIS

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Considerable improvements in the equipment used for differential thermal analysis in recent years have resulted from work in various laboratories. As a consequence the method is finding a constantly broadening application.

In this paper, equipment is described which is designed to further increase the utility of thermal analysis in connection with statistical studies. Through the adaptation of standard recording devices and a program controller to a multiple specimen holder it has been arranged to secure six differential thermal curves at once. With this apparatus a large number of determinations may be made in a relatively short period, as many as twenty-four curves being obtainable in a day.

The qualitative and quantitative application of this equipment to a variety of minerals are shown by a considerable number of selected curves. As an illustration a differential thermal study of artificial mixtures of kaolinite with various other minerals shows the change in kaolinite percentage to be essentially independent of the chemical nature of the other

components. A "calibration curve" of kaolinite peak amplitude plotted against percent kaolinite in the sample may, therefore, be assumed valid in application to an unknown mixture containing kaolinite for rough quantitative analysis.

STORM KING GRANITE AT BEAR MOUNTAIN, NEW YORK

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The Storm King granite at Bear Mountain, New York, occupies the core of a syncline in the earlier crystalline complex of the Hudson Highlands. It is part of a larger synclinal pluton whose concordance with the NE-plunging structure is shown by conformable relations of contacts and parallel mineral alignment in both the granite and the country rocks.

Uniform composition, flow structures of early hornblende crystals and inclusions confined to the marginal portions of the granite indicate magmatic intrusion. Absence of secondary foliation and lack of tectonic fabric patterns in the granite suggest essentially post-tectonic emplacement. The concept of "exchange of space" between the rising magma and the country rocks subsiding into the emptying magmatic chamber is proposed to account for the lack of evidence indicating lifting of the overlying rocks by forcible injection of the granite.

In contrast to most fusion tectonites described in the literature, quartz *c*-axes do not have clearly preferred orientations. Anomalous relations between dimensional and lattice orientation of the larger quartz grains are tentatively explained by differential solution of quartz by hydrothermal end-stage products of magmatic (Storm King granite) origin.

Field and statistical studies of principal joint systems reveal significant concentrations of longitudinal, cross and diagonal fractures. Joint patterns in the Storm King granite and in the Highlands Complex are nearly identical. Several possible mechanisms are discussed to explain their development.

The tectonic history of the region is traced. Interpretation of faults in conjunction with other structural data is used to distinguish between the effects of pre-Cambrian and Paleozoic deformation intervals.

OXIDATION AND REDUCTION IN GEOCHEMISTRY

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The concept of oxidation-reduction potentials is capable of wide application in the study of geochemistry and mineral paragenesis. Many elements occur in different oxidation states in the earth's crust, and oxidation-reduction potentials give a quantitative expression for the conditions of stability of these different oxidation states. Reactions involving oxidation and reduction are particularly important in the formation of minerals from aqueous solutions at or near the earth's surface. The groundwater table often forms a sharp boundary between an upper zone of high oxidation potential and an underlying zone of relatively low oxidation potential.

The significance of oxidation-reduction potentials in geochemistry is particularly marked in the way in which rare elements are often concentrated and enriched in deposits formed under extreme oxidizing or reducing conditions.

CUSPIDINE IN THE SYSTEM $\text{CaO} \cdot \text{SiO}_2 \cdot \text{CaF}_2$

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The reported occurrence of cuspidine ($\text{Ca}_4\text{Si}_2\text{O}_7\text{F}_2$) in but three localities, two of which are in volcanic areas, would indicate it to be a rare mineral. Cuspidine, however, has been

identified as such in basic open hearth steel slags and in finishing slags from electric steel furnaces. In electric furnace slags, cuspidine is associated with larnite, merwinite, or with pseudo-wollastonite.

To determine the equilibrium relations of cuspidine, ten gram samples covering a wide range in composition of CaO , SiO_2 and CaF_2 were melted in platinum and in graphite crucibles. Cuspidine formed readily in these melts, being associated with the same minerals as in the slags. The actual mineral composition did not agree however with calculated compositions based on a simple chemical reaction between the three components. The actual mineral composition indicated a loss in silica.

Melts made from pulverized quartz and fluorite in graphite crucibles yielded well-crystallized cuspidine. The graphite crucibles in the muffle furnace were surrounded by a thick matt of fibrous silica which in some cases covered the crucible and the lid. The loss in weight of the original constituents was determined, and from the identification of the resultant phase this reaction follows:



The deposit of silica surrounding the crucible is caused by the reaction of the SiF_4 with the water vapor in the products of combustion.

Attempts to determine the melting point of pure cuspidine in a quenching furnace were unsuccessful, the cuspidine being converted to a mixture of dicalcium silicate and lime and sometimes tricalcium silicate.

The reaction



accounts for this phenomenon. Further evidence for this reaction lies in the abundant presence of gas bubbles imbedded within the dicalcium silicate crystal fragments.

The volatilization of silicon tetrafluoride accounts for the anomalous results obtained in a previous investigation.

CHARTING FIVE, SIX, AND SEVEN VARIABLES ON HYPERTETRAHEDRAL FACES*

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Three variables may be charted in a triangle by the use of trilinear coordinates, and four variables in a tetrahedron by means of quadrilinear coordinates. This unique property of the triangle and tetrahedron suggests that a similar property exists for hypertetrahedra of n dimensions.

By mathematical induction, it is possible to predict the number of vertices, edges, triangular faces, tetrahedra, and hypertetrahedra that bound an n -dimensional hypertetrahedron. A tabulation of these boundaries, up to the ninth dimension, is given. The number of vertices in each hypertetrahedron corresponds to the number of variables that may be charted within it. Hypertetrahedra of 4, 5, and 6 dimensions, having 5, 6, and 7 vertices are bounded respectively by 10, 20, and 35 triangular faces.

Two methods exist for charting 4 variables in a tetrahedron. From a number of sets, a surface may be geometrically constructed or analytically deduced; and a topographic map of this surface may then be drawn. A second method is to develop the tetrahedron onto a plane, and merely to plot the triads 123, 124, 134, and 234, each recomputed to 100 percent. The first method is inapplicable to hypertetrahedra, and the second method may not

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be exactly applied, as hypertetrahedra can not be developed. The triangles bounding the hypertetrahedra, however, may be arranged empirically, so as to constitute a compound system of trilinear coordinates for charting the triads $1, 2 \cdots (v-1)$, $3 \cdots v$, $2, 3 \cdots (v-1)$, $4 \cdots v$, $3, 4 \cdots (v-1)$, $5 \cdots v$, etc., where v means both vertices and variables.

Coordinate systems of this kind have been prepared for charting 5, 6, and 7 variables. Some choice exists in the arrangement of the triangles, but compactness and the preservation of developed tetrahedra are determining factors that practically eliminate alternative arrangements. Such coordinates may be given algebraic meanings within individual triangles, but not between them. The composite charts, however, afford geometrical pictures, which, if conventionalized, may be as effective as a true system of analytical coordinates.

FUSION OF SANDSTONE BY INTRUSIVE ANDESITE, PALISADES DAMSITE, IDAHO

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During pre-construction investigations at Palisades Damsite, on the Snake River, about 44 miles east of Idaho Falls, Idaho, an irregular sill-like body of hypersthene-augite andesite intrusive into sandstones, siltstones, and claystones at the left abutment has been explored extensively. The andesite is basic (57.9 percent SiO_2), containing microphenocrysts of hypersthene, augite, and labradorite in a groundmass of microcrystalline labradorite, augite, and magnetite with interstitial glass. Secondary clay minerals ranging from montmorillonite to nontronite occur in the groundmass, having formed from the primary minerals and glass, and in voids and fractures. Calcite veins $1\frac{1}{4}$ inches wide are present. Well-developed crystals of tridymite, possibly the variety of christensenite, occur in voids, and apparently formed later than associated nontronite.

As indicated by drill cores, the andesite-sediment contact is irregular, varying from highly contorted to relatively plane, typically transgressing stratification. In several places, sandstones at the contact have been partially fused and caused to flow. Particles of sediments enclosed by andesite are partially digested and surrounded by reaction products. In one occurrence volcanic glass penetrates sandstone more than 1 inch. Locally the sediments are affected through an 8-foot wide zone.

The partially fused sandstones are gray, vesicular, massive to flow-banded, and very hard. In one occurrence, the fused material is intruded upwardly into adjacent indurated sediments. Microscopically, the grains of sand are observed in an isotropic or cryptocrystalline matrix; minute prisms of secondary pyroxene are present. Vesicles are ellipsoidal, as large as 3.0 mm. in diameter, and are lined or partially filled with tridymite.

RELATION OF MINOR INTRUSIVES TO GRANITE IN THE BRYCE AREA, ONTARIO

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A petrographic and chemical study is presented of sodic porphyries, lamprophyres, and granitic rocks in the vicinity of Bryce township, Ontario. It is concluded that the minor intrusives crystallized from a late extract of the granite batholith, modified by reaction with the country rock. This conclusion is supported by field evidence and by the textures, chemistry, and mineralogy of the rocks involved. An attempt is made to correlate these results with the intrusives of the Kirkland Lake area which lies on the north side of the granite batholith in question.

ZONED METASOMATIC GNEISSES RELATED TO STRUCTURE AND TEMPERATURE,
LARAMIE RANGE, WYOMING*

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During geologic work in the Laramie Range, southeastern Wyoming, from 1945 to 1947, an area of pre-Cambrian metasomatic gneisses was mapped in detail. The gneisses, which are dioritic to granitic, replace metagabbro schist. A zonal variation of gneisses occurs along strike, with highest temperature facies in the most open structure and lowest in the tightest structure. This is indicated by percentage variations of plagioclase, anorthite content, potash feldspar, pyroxene, and biotite. Abrupt lithologic variations across strike reflect time intervals of shearing. Mineral zoning and relation to structure are analogous to these features in ore deposits.

Migration of K and other ions upward and laterally by diffusion through liquid in shear fractures, or by surface diffusion along planar structures and in the solid state, drove out Mg, Fe, and other elements from metagabbro schist. Numerous cordierite bodies formed by advancing metasomatism in metagabbro schist. Under certain conditions of similar metasomatism minor elements such as Zn, Pb, and other metals in host rock silicates, should be prohibited in part from entering the crystal lattice of newly-formed silicates, and move upward to form ore deposits. None is present here possibly because of high temperature, kind of silicates, and rapidity of crystal formation. Pegmatites, other than occasional small granites, are lacking—an absence related to the high thermal gradient.

Metasomatic gneisses which replace hornblende schist 25 miles northwest contain more potassic facies on more open parts of structure; tighter portions have facies higher in lime and soda.

The first example of zoning formed against relatively cool, the second against relatively hot, host rock.

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FRANCKEITE IN RELATION TO LENGENBACHITE

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The symmetry of francckeite was described as orthorhombic, pseudo-tetragonal (Ahlfeld, Himmel & Kleber, 1935) on the basis of goniometric measurements on poor crystals from the Porvenir vein, Huanuni, Bolivia. Rotation and Weissenberg photographs of a crystal from this locality show monoclinic symmetry and lead to a cell with $a=46.85$, $b=11.62$, $c=17.28$ kX, $\beta=94^\circ48'$; cell content $16[5\text{PbS} \cdot 3\text{SnS}_2 \cdot \text{Sb}_2\text{S}_3]$.

The rotation photograph indicates the presence of a pseudo-period with $b'=b/2$. The Weissenberg resolutions of the layers ($h0l$) and ($h2l$) show well-defined spots and continuous curves with h a multiple of 8. Hence there is a pronounced pseudo-cell with $a'=a/8$, $b'=b/2$, $c'=c$. The films bear a striking resemblance to those obtained on lengenbachite, $6\text{PbS} \cdot (\text{Ag}, \text{Cu})_2\text{S} \cdot 2\text{As}_2\text{S}_3$ (Nuffield, 1944), a mineral with similar habit and cleavage. Here, however the layering is a multiple of 6. Data for the pseudo-cells of the two minerals compare as follows:

	a'	b'	c'	β	Z	G(calc.)	G(meas.)
Franckeite	5.86	5.81	17.28	$94^\circ48'$	1	5.87	5.88
Lengenbachite	5.80	5.745	18.36	$94^\circ19'$	1	5.78	5.80

Obviously these two minerals are related structurally although quite different chemically.

CONDUCTIVITY OF DILUTE WATER SOLUTIONS NEAR THE CRITICAL TEMPERATURE

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Attempts to measure the conductivity of water and solutions of low concentration through the critical temperature are described. The methods employed include tubular stainless steel bombs with electrodes introduced through insulating connectors. Various frequencies from 60 to 10,000 cycles per second have been applied. The conductivity is measured with an impedance bridge. Results to date are reported showing increasing conductivity with rising temperature in the liquid state until the critical region is approached; a much lower order of conductivity for the vapor phase but increasing also. The two curves approach each other in the critical region, and appear to join in such a way as to indicate a transitional range of several degrees rather than a single critical temperature. Difficulties inherent in the method are presented and criticism and suggestions are invited.

The investigations are being conducted as part of a research contract with the Signal Corps Engineering Laboratories which calls for experimentation in the artificial crystallization of quartz of a size useful for piezoelectric purposes.

FELDSPAR INTRODUCTION IN THE RED RIVER DISTRICT, NEW MEXICO

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The border facies of the pre-Cambrian granite bodies in the Red River-Twining area of northern New Mexico show clearly the methods of introduction of potash feldspar into metamorphic rocks, especially into amphibole schists and gneisses. A few scattered grains of bright salmon-colored feldspar with quartz were first noted along narrow cracks, either parallel to or transverse to the foliation of the metamorphic rocks. The salmon-colored feldspar permeated the country rocks from such tiny fractures, and apparently replaced the pre-existing minerals. The process became more and more intense until the resulting rocks resembled a gneissic granite. The grains of the introduced feldspar range from microscopic in size to crystals more than three inches long; the average is probably about $\frac{1}{4}$ inch. Muscovite and albite feldspar are commonly introduced in small amounts with the potash feldspar, and locally black tourmaline is present. Deposition of the feldspars is thought to have taken place under a cover of several thousand feet. The potash-bearing fluids were not channelled along well-defined open fissures or faults, but rather soaked through all available openings in the metamorphic rocks. The extent of the feldspar introduction by replacement is hypothetical as evidence has been recognized only along the borders of the granite. Feldspars within the interior of the mass are, however, identical in composition and texture with those on the borders.

HEXAGONAL ZONAL EQUATIONS

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Two zonal equations are presented. The first uses Bravais indices where $p_0 = \frac{1}{3}$, c/a and $\pi_0 = \frac{2}{3}$, $c/\sqrt{3}a$, and $h+k+i=0$ and $(h+2k)+(2h+k)+(h-k)=0$. This requires simultaneous equations involving three sets of rectangular axes.

The second uses Klein indices where $p_0 = \frac{2}{3}$, c/a and $\pi_0 = \frac{2}{3}$, $c/\sqrt{3}a$, and $h+k+i=0$ and $(h+2k)+(2h+k)+(h-k)=0$, but $h+k+i+(h+2k)+(2h+k)+(h-k)=0$. This gives equations involving a vertical axis and two sets of three horizontal axes.

Both equations are heptaxial. In the gnomonic projection u/w and v/w are shown as ratios between p_0 and π_0 and the zonal intercepts. It is impossible to use Klein axes with Bravais indices or Bravais axes with Klein indices.

SCORZALITE AND SOUZALITE, TWO NEW PHOSPHATE MINERALS ASSOCIATED
WITH BRAZILIANITE, MINAS GERAIS, BRAZIL*

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The paper describes two new phosphate minerals associated with brazilianite from the original brazilianite-bearing pegmatite near Divino, Minas Gerais, Brazil. The new minerals are named in honor of Dr. Evarista Scorza and Dr. Antonio José Alves de Souza, both of the Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil.

Scorzalite is a massive, blue hydrous iron magnesium aluminum phosphate with the formula $R_2O_3:RO:P_2O_5:H_2O$; chemical analysis: $Al_2O_3=30.87$; $Fe_2O_3=0.54$; $TiO_2=0.10$; $FeO=14.74$; $MgO=4.23$; $MnO=0.11$; $P_2O_5=42.90$; $H_2O+=5.86$. The x-ray powder pattern of scorzalite is identical with lazulite and the two minerals form a continuous series arbitrarily separated where the Mg-Fe molecular ratio is 1:1; Specific gravity is 3.33; Biaxial (-), 2V med-large; X near 1.637; Y near 1.663; Z near 1.673; Monoclinic; Cleavage (110); Twinned (100); $Z=b$; X near c ; no crystals available for study.

Souzalite is a fibrous, green hydrous iron-magnesium-aluminum phosphate with the formula $2R_2O_3:3RO:2P_2O_5:5H_2O$. The mineral is a hydrothermal alteration product of, and more abundant than, scorzalite in the pegmatite. Chemical analysis: $Al_2O_3=26.07$; $Fe_2O_3=2.65$; $TiO_2=0.07$; $FeO=11.49$; $MgO=9.62$; $MnO=0.31$; $P_2O_5=37.70$; $H_2O+=12.04$. The x-ray powder pattern is unlike any known phosphate. Specific gravity is 3.087; Biaxial (-); 2V medium; Dispersion, extreme; X near 1.623; Y (blue) near 1.640; Z near 1.652; Monoclinic (?), Cleavage (010); twinned (100); $X=b$ and Z near c . No crystals available for study.

The mineral assemblage includes albite, muscovite, quartz, apatite, zircon, and tapiolite, and the pegmatite can be subdivided into a central and border zone, each displaying characteristic texture, structure, and mineralogy.

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TELESCOPED, XENOTHERMAL MINERAL ASSOCIATION IN ALKALIC PEGMATITES AND
RELATED VEINS, VERMICULITE PROSPECT, BEARPAW MOUNTAINS, MONTANA*

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Pegmatites and veins genetically related to an early Tertiary, potash-rich syenitic magma, are intrusive into fractured syenitic porphyry and fine-grained alkalic monzonite in the Rocky Boy composite stock, at the site known as the Vermiculite Prospect, near the head of Big Sandy Creek, Bearpaw Mountains, Montana.

The complex mineral assortment of these deposits represents an alkalic counterpart of the quartz-rich deposits in other regions that have been called telescoped and xenothermal by Spurr, by Buddington, and by other writers. The pegmatites and related veins at the Vermiculite Prospect are believed to have formed at a depth of from 3,000 to 5,000 feet under conditions of rapid fall in temperature.

Silicate minerals include sanidine (in pegmatites) and adularia (in veins); aegirite, biotite, sphene, and zircon. Oxide minerals include magnetite, ilmenite, hematite, brookite, and perovskite. Sulfide minerals include pyrrhotite, pyrite, galena, chalcopyrite, and sphal-

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erite. Calcite is abundant. Other minerals include apatite, chlorite, fluorite, barite, celestite, apophyllite, and analcime.

Under action of surface waters the biotite has been locally altered to vermiculite, especially in the vicinity of pyrrhotite, and in some places it has been leached of its bases to form brittle, white plates.

UNIT CELL OF MALACHITE

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The unit cell data for malachite given in the literature are those of Brasseur (1932), and were obtained from rotation photographs. Weissenberg photographs confirm his cell dimensions, but indicate a considerable difference in the value of the angle β . Brasseur used the crystallographic value of $91^{\circ}03'$ (Goldschmidt setting), and apparently indexed his films on this basis.

Measurements on Weissenberg photographs, with rotation both about the c and b axes, give a value for β of $98^{\circ}45'$. Because of the large value of d_{100} and the small value of c_0 , this is nearly the maximum angle possible. An angle of about 100° would be equivalent to a B-centered orthorhombic cell, with a doubled value for d_{100} .

The cell dimensions as found are:

$$\begin{aligned}a_0 &= 9.42 \text{ \AA} \\b_0 &= 11.87 \quad \beta = 98^{\circ}45' \\c_0 &= 3.21\end{aligned}$$

SYNTHESIS OF LEAD SULPHANTIMONIDES

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Lead sulphantimonides were synthesized by dry fusion in vacuum and from various aqueous solutions in a closed system at temperatures up to 425°C . and at pressures up to 2000 bars, and the products were correlated with natural minerals by x-ray powder and Weissenberg photographs. Only two lead sulphantimonides were synthesized by dry fusion in vacuum: boulangerite and mineral 'X', a new mineral from the Red Bird mine, Nevada, which has not as yet been named. From aqueous solutions artificial equivalents of fulopite, pligionite, semseyite, zinkenite, and mineral 'X' were synthesized, together with two other lead sulphantimonides for which natural counterparts are unknown. Products of hydrosynthesis were sealed in vacuum and subjected to temperatures below their melting points (about 380°C .) for a period of two weeks. Outward crystal forms of these products remained unchanged, but in every case partial to complete alteration to boulangerite, mineral 'X' or galena, with deposition of a brown sublimate of stibnite, had occurred.

The minerals reproduced by hydrosynthesis are typical of the epithermal environment; minerals of mesothermal association were not obtained in this way. Sulpho-salts form most readily from alkaline and variably sulphurous solutions; acid solutions result in deposition of lead and antimony sulphides with, rarely, traces of lead sulphantimonides. Neutral chloride salts facilitate formation of these sulpho-salts; carbonates and bicarbonates repress such formation.

GARNET-IDOCRASE ROCK, A PSEUDO-JADE FROM PLACER COUNTY, CALIFORNIA

AUSTIN F. ROGERS

Stanford University, California

A massive rock occurring in connection with serpentine proves on optical examination to be an intimate mixture of grossularite and idocrase. The idocrase occurs in minute por-

phyroblasts disseminated through the granoblastic garnet and is apparently a product of retrogressive metamorphism.

The color of the rock varies from white and gray to greenish gray and has interesting brownish red mottlings. It is an attractive ornamental stone especially in thin slabs by transmitted light.

It is essentially different from californite although the latter term might be expanded to include it.

Attention is called to the variability of idocrase in various occurrences.

MINERALOGY OF THE BALLAST SANDS OF JAPANESE BALLOONS*

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The beach sands of the Japanese balloons dispatched to this country in great numbers were submitted to the Section of Military Geology of the U. S. Geological Survey. Detailed studies indicated that these showed such an unusual suite of minerals that it would be possible to indicate their probable source on the coast of Japan. The minerals of these sands and their characteristics will be described in detail.

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PRESENT STATUS OF LABORATORY STUDIES OF DRY SILICATE SYSTEMS

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Phase equilibrium studies of dry silicate systems, which are now in progress or have just been completed at Geophysical Laboratory, yield much information on the ranges in chemical composition and on the mutual stability relations at elevated temperatures of several groups of important rock-forming minerals—particularly the olivines, pyroxenes, pyroxenoids, melilites, feldspars, and feldspathoids. Progress on the following systems is reported: $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$, $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$, nepheline-potash nepheline-silica, leucite-anorthite-silica, leucite-forsterite-silica, nepheline-diopside-silica, nepheline-anorthite-silica, $\text{CaO}-\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$, $\text{CaO}-\text{MgO}-\text{FeO}-\text{SiO}_2$, $\text{K}_2\text{O}-\text{MgO}-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$.

TEMPERATURE OF FORMATION FROM FLUID INCLUSIONS

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In collaboration with Dr. F. G. Smith a simple technique has been developed whereby primary liquid and gas inclusions in a mineral may be utilized to determine its approximate temperature of formation. The mineral is prepared by crushing and screening and is placed in an electric furnace whose temperature is steadily increased. The temperature at which the expanding liquid just fills the cavity is accepted as the temperature of formation and is usually determined visually with the microscope; in the present procedure, the frequency and volume of exploding inclusions is recorded, providing data from which the temperature is interpreted. By this means the temperature of formation of quartz in the Ivigtut (Greenland) cryolite deposit was determined as at least 320°C . The inversion temperatures of several minerals studied, including quartz and cryolite, have a marked influence on the audible effect, and inversion points may in some cases at least be predicted from this effect alone.

PARAGENESIS OF THE GARNET AND ASSOCIATED MINERALS OF THE BARTON
MINE NEAR NORTH CREEK, N. Y.

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During the spring and late summer, the writer made his first post-war visits to the Barton Garnet Mine on Gore Mt. near North Creek, N. Y., and during these visits a number of specimens of the garnet and associated minerals were collected for a paragenetic study which was suggested by the occurrence of hypersthene crystals up to four inches in length extending from their attachment in the hornblende rims into the garnet masses. These vary in size up to a foot in cross section. Other hypersthene crystals up to one and a half inches in length were completely inclosed within the garnet.

In addition to the usual rather thick envelope of hornblende surrounding the garnet a commonly occurring thin envelope of plagioclase feldspar appears between the hornblende and garnet. The feldspar sometimes produces envelopes or irregular masses up to an inch thick. Euhedral crystals of hypersthene and terminated crystals of hornblende are associated with the larger masses of feldspar. A number of other minerals occur at the contacts and/or wholly within the plagioclase or garnet.

The textural and structural relationships suggest that the direction and order of crystallization was centripetally from the surrounding mass of the inclosing gabbroic rock to the garnet which, except for the acid plagioclase, was the last mineral to crystallize.

USE OF FELDSPAR IN THE PETROFABRIC ANALYSIS OF IGNEOUS ROCKS

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Microscopic statistical analysis has not kept pace with granite tectonics as a tool in the structural study of igneous rocks. The methods of petrofabrics are rarely applied to igneous problems and when used rely chiefly on studies of quartz and the micas.

The omnipresent feldspars are readily oriented with the five-axis Universal Stage and are more useful in studies of igneous rocks than the more restricted quartz and mica. Although the elements in the feldspars suitable for measurement are limited by the variable relations of the indicatrix to crystallographic directions and by twin relationships, several elements give reliable data. Measurements of both lineation and foliation can be made on the same mineral.

Adaptations of the Fedorov plagioclase stereograms permit measurements to be made on an easily oriented crystallographic element while the plotting may be done for a more desirable element or section. Petrofabric data are more easily interpreted if included as a part of the structural map and sections.

Study of a granitic intrusive in north-central Wisconsin by both megascopic and microscopic methods indicates that the two methods complement each other and that microscopic data may be used where megascopic data are incomplete or lacking. Microscopic analysis frequently reveals several structural elements where only the dominant one may be visible in outcrop.

GOLD CRYSTALS FROM THE SOUTHERN APPALACHIANS

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Gold in well-formed rhombic dodecahedra is reported for the first time from the Southern Appalachians. The crystals were obtained from placer deposits in Greenville County, South Carolina. Poorly-developed octahedra, dendritic forms and wire gold have been re-

ported from Georgia. Euhedral gold crystals are extremely rare compared with the amount of the metal produced and very few have been preserved.

Euhedral crystals and filiform gold develop in open spaces, for gold is too soft and malleable to displace most other minerals. Also because of these properties crystalline structure is readily destroyed by impact or even by polishing, but the high mobility of the atoms makes recrystallization easy. Euhedral crystals are deposited from solutions occupying the cavities. Wire-like forms of the native metals result when the material for growth is available in only one direction, the wires being pushed out into the cavities by the addition of atoms at their base from solutions occupying small pore spaces in the walls.

RÔLE OF ALUMINUM IN THE ROCK-FORMING SILICATES

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In the rock-forming silicates aluminum may appear in either six-fold (octahedral) or four-fold (tetrahedral) coordination with oxygen. Octahedrally coordinated aluminum is structurally like magnesium or ferrous or ferric iron. Tetrahedrally coordinated aluminum is structurally like silicon.

A survey has been made of the geologic distribution of tetrahedrally and octahedrally coordinated aluminum. It has been found that minerals containing tetrahedrally coordinated aluminum are characteristic of igneous rocks, thermally metamorphosed rocks, high-grade regionally metamorphosed rocks and the products of artificial melts. Minerals containing octahedrally coordinated aluminum are characteristic of weathering products, sedimentary rocks, hydrothermal deposits, deuteric alterations, and low and middle grade regionally metamorphosed rocks (stress minerals). It is apparent that at high temperatures aluminum tends to be tetrahedrally coordinated and at low temperatures octahedrally coordinated. The effect of hydrostatic pressure is less obvious but octahedral coordination is more economical of space.

The presence of other ions in a mineral, particularly the alkalis, seems to be important. In potassium-aluminum silicates there is always at least one tetrahedrally coordinated aluminum ion for each potassium ion present. The same holds true for the sodium-aluminum silicates except in the pyroxene, jadeite, and the corresponding amphibole, glaucophane.

Rock and mineral relationships considered in the light of aluminum coordination include kyanite-andalusite-sillimanite-mullite, epidote-plagioclase, and gabbro-eclogite. On the assumption that the linking of silicon tetrahedra is favored by low temperature and low pressure, and that high aluminum coordination is favored by low temperature and high pressure it is possible to derive, theoretically, mineral facies essentially similar to those of Eskola.

PYROSYNTHESIS OF TELLURIDE MINERALS

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In connection with a comprehensive study of the telluride minerals an attempt was made to reproduce most of the established and reported species by fusing the powdered elements in the proper proportions in evacuated silica glass tubes. The following compositions gave practically homogeneous compounds which were proved to be identical with the corresponding minerals by microscopic and x-ray examination: AuTe_2 (calaverite), Ag_3AuTe_2 (petzite), Ag_2Te (hessite), Ag_5Te_3 or Ag_{2-x}Te (empressite), Cu_6Te_3 or Cu_{2-x}Te (weissite), Cu_4Te_3 or Cu_{2-y}Te (rickardite), NiTe_2 (melonite), FeTe_2 (frohbergite), PbTe (altaite), HgTe (coloradoite), Bi_2Te_3 (tellurbismuth), BiTe or $\text{Bi}_{2+x}\text{Te}_{3-x}$ (wehrlite). (Ag,

Au)+Te ("muthmannite") gave $\text{AuTe}_2 + \text{Ag}_3\text{AuTe}_2$. $\text{Ag}_4 + \text{Te}$ ("stuetzite") gave $\text{Ag}_2\text{Te} + \text{Ag}_2$. $\text{Pt} + \text{Te}_3$ ("niggliite") gave $\text{PtTe}_2 + \text{Te}$. Some natural tellurides dissociate on heating and cannot therefore be reproduced by fusion.

A NEW HYDROTHERMAL QUENCHING APPARATUS

O. F. TUTTLE AND N. L. BOWEN

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A simple apparatus has been developed for the study of equilibrium relations at high temperatures and pressures in mineral systems including volatile components. Investigations have been carried to pressures of 30,000 lbs. per sq. in. (approximately 4.5 miles depth) at temperatures up to 900°C. Results on the system $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$ show that a water pressure of 15,000 lbs. per sq. in. lowers the liquidus about 100°C. in the orthoclase field. In compositions approaching the quartz-orthoclase join a pressure of 30,000 lbs. per sq. in. gave relatively insignificant additional lowering.

PARTLY VITRIFIED XENOLITHS IN PILLOW BASALT*

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Department of Mines, Victoria, Canada

Pillow basalt in the Tuya Range of northern British Columbia contains many xenoliths of granite and a few of quartzite. The feldspar and quartz of the granite inclusions are highly cracked and, together, have yielded abundant colourless glass with a refractive index of 1.495. Some of the feldspar grains which have been partly vitrified are cut by glass veinlets that form extremely fine meshworks. The ferromagnesian minerals have been converted almost completely to a dark brown glass containing scattered new crystals of clinopyroxene and black opaque minerals. A small proportion of the quartz contains tridymite in minute veinlets of glass. The quartzite inclusions show partial vitrification, some introduction of basic pale brown glass chiefly along grain boundaries, and the formation of sanidine, cordierite, hypersthene, and clinopyroxene. A fragment of granite in basaltic agglomerate is also partly vitrified and contains the new minerals: clinopyroxene and anorthoclase. The temperatures attained by the xenoliths did not exceed 1075°C but were probably greater than 900°C.

* Published with the permission of the Chief Mining Engineer, British Columbia Department of Mines.

ROCK ALTERATION ASSOCIATED WITH THERMAL SPRINGS*

DONALD E. WHITE

Carson City, Nevada

The study of rock alteration and its relation to ore-bearing solutions can be approached in a number of different ways. Each general method is examined briefly and the need for a close integration of all methods is emphasized.

The study of processes taking place in areas of thermal springs is one approach. In such areas there is opportunity to investigate several specific types of alteration as well as the physical state, temperature, composition, and concentration of each associated solution. General conditions at Steamboat Springs, Nevada, are described; rocks above the general

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water table are being altered by sulfuric acid resulting from the oxidation of H_2S , and rocks below the water table are being more slowly attacked by the saline spring waters. Outstanding studies by other men are summarized.

ISOTOPE RATIOS, A CLUE TO THE AGE OF CERTAIN MARINE SEDIMENTS

FRANS E. WICKMAN
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If an element A has a radiogenic isotope A_1 and a nonradiogenic A_2 , the ratio A_1/A_2 is an index of the age of marine chemical sediments, if the content of the isotope B^* producing A_1 can be neglected. It is shown that the method can be used for strontium (and perhaps Pb^{208}) on limestones and anhydrites.

STABILITY RELATIONS OF GROSSULARITE

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Experiments of an exploratory nature have been conducted to determine the range of stability of grossularite garnet, $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$. The following techniques were applied: thermal and differential thermal analysis, high pressure and temperature bombs, hydrothermal bombs, and powder metallurgical sintering techniques. Natural grossularite decomposes in the solid state into gehlenite, wollastonite, and anorthite between 1000°C . and 1100°C . The three resulting minerals are essentially a eutectic mixture below 1265°C . Using both synthetic and natural materials, the decomposition products were found to be stable at least as low as 800°C . This result is dependent on the variables in the diffusion process. The P-T diagram indicating the range of stability of grossularite in the system $\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ has been derived theoretically and determined in part experimentally. The decomposition products are stable above 1028°C . at pressures up to 4100 atmospheres. The nature of the substitution solid solution series $\text{Ca}_3\text{Al}_2(\text{OH})_{12}-\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$, in which the minerals grossularite, plazolite, hibschite, grossularoid, and hydrogrossular occur, is confirmed. An irreversible, endothermic reaction takes place in "pure" natural grossularites in the vicinity of 1000°C . This is thought to be the release of the hydroxyl groups as water, the more hydroxyl, the lower the temperature of release. It is recommended that all garnets be analyzed for H_2O_+ . Although grossularite may form at high pressures in dry systems, its hydrothermal nature should be emphasized.

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Escuela de la Ingeniera de la Universidad de Cuyo, San Juan, Argentina.

Fabrica de Ladrillos Industriales y Refractories, S.A., Monterrey, N. L., Mexico.

Faculté Polytechnique de Mons, Bibliothèque, Rue de Houdain, Mons, Belgium.

Felix Montenegro, Inc., Bais, Negros, Oriental, P. I.

Fondation Universitaire, Library, 11 Rue d'Egmont, Brussels, Belgium.

Foote Mineral Company, 10 East Cheltenham Avenue, Philadelphia 44, Pennsylvania.

Ford Motor Company, Library, Engineering Laboratory, Dearborn, Michigan.

Free Public Library, Fourth & "D" Sts., San Bernardino, California.

Fresno State Teachers College, Library, Fresno, California.

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Garden State Minerals, 1034 Bloomfield Street, Hoboken, New Jersey.

General Chemical Company, L.H. Lab. Library, P.O. Box 149, Long Island City, N. Y.

General Electric Company Laboratory, Library, Pittsfield, Massachusetts.

General Electric Company, Research Laboratory Library, Schenectady, New York.

General Electric Company, Research Laboratories, Wembley, England.

Geological Museum, Trondhjemsveien 23, Oslo 45, Norway.

Geological Society of America, 419 West 117th Street, New York 27, N. Y.

Geological Society of London, Library, Burlington House, Piccadilly, London W. 1, England.

Geological Survey of Egypt, The Director, Darwin Post Office, Cairo, Egypt.

Geological Survey of Great Britain, Library, Exhibition Road, London SW 7, England.

Geological Survey of India, Director, 27 Chowringhee Road, Calcutta, India.

Geological Survey of Kiangsi, Pei-Hwa-Chow Road, Nanchang, China.

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Geophysical Laboratory, 2801 Upton Street, N.W., Washington 8, D. C.
Georgia Dept. of Mines, Mining and Geology, 425 State Capitol, Atlanta, Georgia.
Georgia School of Technology Library, Atlanta, Georgia.
Gleerupska, A. B., Univ.-Bokhandeln, Lund, Sweden.
Gosinoizdat, Nova-Alekseevskaja 52, Moscow 164, U.S.S.R.
Gos Nauch. Biblioteka, Min. Vys. Obrazovaniya, Pl. Nogina, 2/5 pod., Moscow, U.S.S.R.
Gosudarstvennaja Biblio-teka SSSR, im Lenina, ul. Kalinina, 3, Moscow, U.S.S.R.
Government Metallurgical Laboratory, University of the Witwatersrand, Johannesburg, South Africa.

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Haagens, Gerard E., Room 607, 597 Fifth Ave., New York 17, N. Y.
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Hoganas-Billesolms A/B, Biblioteket, Hoganas, Sweden.
Hungarian Libraries Board, Dr. Stephen Gall, Librarian, Budapest IV, Ferenciek-Terre 5, Hungary.
Hunter College Library, 695 Park Avenue, New York 21, New York.

Idaho University Library, Moscow, Idaho.
Illinois State Geological Survey, 419 Natural Resources Bldg., Urbana, Illinois.
Imperial Chemical Industries, Ltd., Alkali Division, Supply Dept., Northwich, Cheshire, England.
Imperial Chemical Industries, Ltd., Billingham Division, Library, Main Offices, Billingham, Co. Durham, England.
Imperial College of Science and Technology, South Kensington, 18 Cromwell Place, London S.W. 7, England.
Indiana University Library, Bloomington, Indiana.
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Industrial Distributors, Ltd., Diamond Research Department, St. Andrew's House, 32-34 Holborn Viaduct, London, E.C. 1, England.
Institut du Petrole, Service de Documentation, 2 rue de Lubeck, Paris 16, France.
Instituto de Biologia e Pesquisas Tecnologicas, Caixa Postal 357, Curitiba Est. Parana, Brazil, S. A.
Instituto de Geologia, Casilla 2777, Santiago, Chile, S. A.
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 Koninklijke Bibliotheek, Lange Voorhout 34, The Hague, Holland.
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 Belge, Africa.
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 Metal Mining Administration, National Resources Commission, North Chungshan Road,
 Hungchiso, Nanking, China.

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- Milwaukee Public Library, 814 West Wisconsin Ave., Milwaukee 2, Wisconsin.
- Mineral Exploration Bureau, National Resources Commission of China, 3 Chiangchun-miao, Tingchiachiso, Nanking, China.
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- Ministry of Supply Director, Royal Aircraft Establishment, Farnborough Hants, England.
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- National Geological Survey of China, Peiping Branch, 9 Ping Ma Ssu, West City, Peiping, China.
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- National Museum, Russell Street, Melbourne C 1, Victoria, Australia.
- National Pei-Yang University Library, Dept. of Geology, Tientsin, China.
- National Tsing Hua University Library, Peiping, China.
- National Tsing Hua University Library, Kunming Office, Yunnan, China.
- Natural History Museum, The Keeper, Mineral Library, South Kensington, London, S.W. 7, England.
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- Naval Ordnance Laboratory Library, Att.: R. C. Hope, Bldg. 172, Room 202-A, Naval Gun Factory, Washington 25, D. C.

- Naval Research Laboratory, Library, Washington 25, D. C.
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 New Mexico State Teachers College, Silver City, New Mexico.
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 Newark Museum, Washington Park West, Newark, New Jersey.
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 Norges Geografiske Undersøkelse, Oslo, Norway.
 Norges Geologiske Undersøkelse, Josefinestgt 34, Oslo, Norway.
 North Carolina State College of Agriculture and Engineering, W. P. Kellam, Librarian, State College Station, Raleigh, North Carolina.
 North Dakota Agricultural College, The Library, Fargo, North Dakota.
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 Ontario Dept. of Mines, Parliament Buildings, Toronto, Ontario, Canada.
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 Pennsylvania State College, School of Mineral Industries, State College, Pennsylvania.
 Philadelphia Mineralogical Society, Academy of Natural Science, Logan Circle, Philadelphia, Pennsylvania.
 Politekhnic. Biblioteka, Glavnij Pochtamt, Pochtovyj jashchik 828, Moscow, U.S.S.R.

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 Presidency College, The Principal, Madras, India.
 Princeton University Library, Princeton, New Jersey.
 Provincial Bureau of Industrial Research, The Library, Chung San Nan Rd., Taipei, Taiwan, China.
 Publichnaja Biblioteka im. Saltykova-Tschedrina, Sadovaja ul. 18, Leningrad, SSSR.
 Publichnoj Biblioteke, Dadovaja, 18, Leningrad, USSR.
 Purdue University Library, Lafayette, Indiana.
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 Queen's University Library, The Douglas Library, Kingston, Ontario, Canada.
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 R. Università, Istituto di Mineralogia, Palazzo Universitario, 5 Modena, Italy.
 R. Università di Padova, Istituto di Mineralogia, Corso Garibaldi g Padova, Italia.
 R. Università di Pisa, Istituto di Mineralogia, Pisa, Italy.
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 Rautatiekirjakauppa Oy (Hukkala), Koydenpunojankatu 2, Helsinki, Finland.
 Reitzels, C. A., Importafd., Norregade 20, Copenhagen K, Denmark.
 Revue de Geologic, M. le Secretaire General, Laboratoire de Geologie, Université de Liège, Liège, Belgium.
- Rhode Island State College Library, Green Hall, Kingston, Rhode Island.
 Rhodes University College, The Librarian, Grahamstown, South Africa.
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 Roth, F. & Cie., S.A., Pepinet 5, Lausanne, Switzerland.
 Royal Ontario Museum of Mineralogy, 100 Queen's Park, Toronto 5, Canada.
 Rutgers University Library, New Brunswick, New Jersey.
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 St. Paul Public Library, Order Department, 4th and Washington Sts., St. Paul 2, Minnesota.
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 Salt Commissioner, Colombo, Ceylon.
 San Diego Society of Natural History, Balboa Park, San Diego, California
 San Diego State College Library, San Diego, California.
 San Francisco Public Library, Civic Center, San Francisco 2, California.
 Santa Ana Public Library, Santa Ana, California.
 Santa Barbara State College, 1920 Lausen Road, Santa Barbara, California.
 Saranac Laboratory, 7 Church Street, Saranac Lake, N. Y.
 Scholtens en Zoon, Groote Markt 43, Groningen, The Netherlands.
 Schortmann's Minerals, 6 McKinley Avenue, Easthampton, Massachusetts.
 Science Museum Library, Accessions Dept., South Kensington, London, S.W. 7, England.
 Scientific Library Division, The Chief, Bureau of Science, Manila, P. I.
 Scripps Institute of Oceanography, The Library, La Jolla, California.
 Sektor Seti Spetz Bib-ka, Akademii Nauk SSSR, Pyzhevskij per 7, Moscow 17, U.S.S.R.
 Señores Banco Minero, Apartado Postal 2565, Lima, Peru.

- Service des Mines, Noumea, New Caledonia.
- Servicio Tecnico de Minería y Geología, Att.: Victor M. Lopez, Ministerio de Fomento, Caracas, Venezuela, S. A.
- Servico de Documentacao, Ministerio da Agricultura, Caixa Postal 915, Rio de Janeiro, Brazil, S. A.
- Servico de Informacao Agricola, Ministerio da Agricultura, Caixa Postal 1523, Rio de Janeiro, Brazil, S. A.
- Servico Geologico Nacional, Apartado Nacional No. 2504, Bogotá, Colombia, S. A.
- Smith, W. H. and Sons, 71-75 Boulevard Adolph Max, Brussels, Belgium.
- Smith College Library, Northampton, Massachusetts.
- Sociedad Científica Argentina, Santa Fe 1145, Buenos Aires, Argentina, S. A.
- Socony Vacuum Oil Company of Colombia, Apartado Aereo 4034, Bogota, Colombia, S. A.
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- Southern Methodist University, Library Dept., Dallas, Texas.
- Southwestern Louisiana Institute, Stephens Memorial Library, Lafayette, Louisiana.
- The Southwest Mineralogists, Att.: Pearle Arnold, Librarian, 2132 West 76th Street, Los Angeles 44, California.
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- Stanford University Library, Stanford University, California.
- State Normal School Library, Gorham, Maine.
- State University of Iowa, Library, Iowa City, Iowa.
- State University of North Dakota Library, University Station, Grand Forks, North Dakota.
- Steven, B. F. and Brown, 28-30 Little Russell Street, London W. C. 1, England.
- Sul Ross State Teachers College, The Library, Alpine, Texas.
- Sveriges Geologiska Undersökning, Stockholm 50, Sweden.
- Syracuse University Library, Syracuse, New York.
- Technical Periodical Club, Att.: Librarian, Bureau of Reclamation, Denver 2, Colorado.
- Technical University of Norway, Geological Department, c/o Professor Dr. Thorolf Vogt, Trondheim, Norway.
- Technicke Knihkupectvi, Janska I, Praha I, Czechoslovakia.
- Tekhn. Biblioteka Glavn, Arkhivnogo Upravlenija, Bolsh. Priogovskaja 17, Moscow, U.S.S.R.
- Tennessee Eastman Corporation, Kingsport, Tennessee.
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U. S. Bureau of Mines, Petroleum & Oil-Shale Experiment Station, Box 621, Laramie, Wyoming.

U. S. Bureau of Standards Library, Washington, D. C.

U. S. Geological Survey, The Librarian, Washington 25, D. C.

U. S. Geological Survey, Regional Geologist, 707 Peyton Building, Spokane 8, Washington.

U. S. National Museum, Washington, D. C.

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Università di Cagliari, Istituto di Mineralogia, Cagliari, Italy.

Università di Firenze, Istituto di Mineralogia, Petrografia e Geochimica, Firenze, Italy.

Universitaetsbibliothek (17a), Heidelberg, American Zone, Germany.

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University of Buffalo Library, 3425 Main Street, Buffalo, N. Y.

University of Calcutta, Secretary, Geological Department, Senate House, Calcutta, India.

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University of California, Division of Soils, 120 Hilgard Hall, Berkeley 4, California.

University of California, Los Alamos Scientific Laboratory, Att.: Project Librarian, P.O. Box 1663, Los Alamos, New Mexico.

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University of Cambridge, Department of Mineralogy and Petrology, Cambridge, England.

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- University of Sydney, Fisher Library, Sydney New South Wales, Australia.

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 Washington State College Library, W. W. Foote, Librarian, Pullman, Washington.
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 Wayne University Library, 4841 Cass Avenue, Detroit 1, Michigan.
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 Wellesley College Library, Wellesley 81, Massachusetts.
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PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY (LONDON)

A meeting of the Society was held on Thursday, January 22, 1948, in the apartments of the Geological Society of London, Burlington House, Piccadilly, W. 1 (by kind permission). The following papers were read: (kindly furnished by G. F. Claringbull, General Secretary):

- (1) *A note on the thermal decomposition of chrysotile.* By Dr. M. H. Hey and Dr. F. A. Bannister.

An x-ray, optical and chemical study of the decomposition products formed by heating chrysotile to 1000° C.

- (2) *Dickite and collophane in the Magnesian Limestone of Durham.* By Dr. K. C. Dunham, Dr. G. F. Claringbull and Dr. F. A. Bannister.

Dickite and collophane, associated with fluorite, baryte, blende and pyrite are described from core-specimens of Magnesian Limestone collected by Mr. A. Fowler and Mr. W. Anderson. The identification of these two minerals has been confirmed by x-ray photographs. The positive birefringence observed in the collophane may be due to form birefringence.

- (3) *Sillenite from South Africa.* By Dr. F. A. Bannister.

- (4) *A simple dichroscope.* By Dr. A. T. J. Dollar.

INTERNATIONAL GEOLOGICAL CONGRESS

XVIII SESSION—GREAT BRITAIN, 1948

The Rt. Honourable Sir John Anderson, P.C., G.C.B., F.R.S., M.P., has accepted the office of Honorary President of the General Organizing Committee for the Eighteenth Session of the International Geological Congress which is to be held in Great Britain in 1948, and will welcome the Delegates and Members at the first meeting of the General Assembly. Professor H. H. Read, F.R.S., President of the Geological Society of London, has succeeded the late Sir Thomas Holland as President of the General Organizing Committee and President-Designate of the Congress.

Some 1,100 geologists from countries overseas, accompanied by about 400 relatives, are expected to attend the Congress. The total attendance, including British geologists, is likely to approach 2,000. Twenty-eight Governments and about 160 universities and scientific institutions have already accepted invitations to be represented by Official Delegates.

The meetings of the Congress will be held during the period August 25th to September 1st, 1948, in the Royal Albert Hall and the Lecture Theatres of the Royal Geographical Society and the Imperial College of Science and Technology.

Sir Edward Bailey, M.C., F.R.S., and Professor O. T. Jones, F.R.S., will deliver special addresses to the General Assembly of the Congress on the subject of the Structural History of Britain.

The list of subjects to be discussed at the Sectional Meetings of the Congress is as follows:—

- A. Problems of Geochemistry.
- B. Metasomatic Processes in Metamorphism.
- C. Rhythm in Sedimentation.
- D. The Geological Results of Applied Geophysics.
- E. The Geology of Petroleum.

- F. The Geology, Paragenesis and Reserves of the Ores of Lead and Zinc.
- G. The Geology of Sea and Ocean Floors.
- H. The Pliocene-Pleistocene Boundary.
- J. Faunal and Floral Facies and Zonal Correlation.
- K. The Correlation of Continental Vertebrate-bearing Rocks.
- L. Earth Movements and Organic Evolution.
- M. Other Subjects.

In addition, problems of African geology will be considered at open meetings of the Association des Services Géologiques Africains; and selected paleontological topics will be discussed by the International Paleontological Union. A series of meetings on Mineralogy and Geology of Clays will be organized in conjunction with the Clay Minerals Group of the Mineralogical Society.

The demand for places on the long geological excursions which are to be arranged between August 7th and September 18th as part of the Congress program is very great, and in addition to the 32 excursions previously announced in the Third Circular five more excursions are being organized. Two of these will visit East Anglia, one will visit Jersey, and two others will demonstrate the general geology of Scotland, and the Hydrogeology of England and Wales. There will also be a series of day and half-day geological excursions, and visits to scientific institutions centered on London, between August 22nd and September 3rd.

Full details of the excursion program, and of other arrangements for the Congress are contained in a Fourth Circular which has now been issued.

All communications should be addressed to the General Secretaries, 18th Session International Geological Congress, Geological Survey and Museum, Exhibition Road, London, S. W. 7.

NOTES AND NEWS

CARBONADO FROM VENEZUELA

PAUL F. KERR,* DONALD L. GRAF,* AND SYDNEY H. BALL†

A dark gray specimen of a compact, tenacious material of superior hardness was recently submitted to the Mineralogical Laboratory of Columbia University. The sample was found by Mr. Robert W. Michael while studying the diamond deposits of the Gran Sabana district of Venezuela. It weighed 20.45 carats and measured approximately $15 \times 10 \times 6$ mm. The occurrence of the material suggested that it might be carbonado, which had not previously been reported from the area. Mr. Michael stated that the specimen was from the Surukun valley and was by no means unique, for "almost every digger in the region carries one as a lucky piece."

VENEZUELAN DIAMOND LOCALITIES AND PRODUCTION

The first diamond was found in Venezuela at the turn of the century and to date the total production has been some 234,000 carats, worth about \$3,420,000. Further, some stones presumably have been smuggled across the Brazilian border, and are not included in this estimate. Three districts in the State of Bolivar produce diamonds; Gran Sabana, El Pao, and the upper Caroni River areas. Venezuela produces from 13,000 to 34,000 carats per year, 75 per cent of this amount, it is reported, being gem material. From 75 to 85 per cent of the production comes from the Gran Sabana district. Most Venezuelan stones are small, but some large ones have been found in Gran Sabana—notably one fine gem stone, the Libertador, of 155 carats, found in 1942.

Like the diamond deposits of Bahia in Brazil, the Venezuelan occurrences are in an area of pre-Cambrian granite gneiss and phyllite, intruded by younger igneous rocks of many different types. Concentrations of diamonds occur in the sand, gravel, and clay fillings of old stream channels (Ahlfeld, 1923). The detrital material in these channels has been derived from erosion of the basal members of the overlying Roraima sandstone, whose age has not been determined, because of the lack of fossils (Connolly, 1927). This sandstone is also the source of many of the diamonds found in the important British Guiana fields to the east. Little is known of the distribution of the intrusives from which the diamonds contained in the Roraima must have been derived. It is of interest that the large production of diamonds in Bahia is also believed to be a second-

* Columbia University.

† Rogers, Mayer and Ball, New York, N. Y.

ary concentration from "hard, yellow sandstones and interbedded conglomerates" (Stutzer and Eppler, 1935, p. 159).

RECORDED OCCURRENCES OF CARBONADO

Carbonado was discovered in the diamond placers of San José, district of Sincora, Brazil, in 1843, but prior to 1846, even when recovered in mining gemstones, it was thrown away. Thereafter, it was exported to Holland in common nail kegs for a time. Its value as an abrasive was increasingly recognized, until fine grades sold for as much as \$185 a carat in the late eighties of the last century. The production has never been large and today approximates 30,000 carats a year. However, between 1926 and 1930 (Stutzer and Eppler, 1935, p. 162) the value of carbonado produced in Brazil was, at its lowest figure, twice that for diamonds of all types produced in the same year. The Brazilian carbonados were said by Bauer (1909) to vary in size from "That of a pea to a mass of 700 or 800 carats . . . the average weight being 30 to 40 carats"; however, most of the stones now appearing on the market are only about 6 carats. The largest carbonado ever found, discovered at Lencoes, Bahia, in 1905, weighed 3167 carats, or slightly more than the Cullinan diamond.

The major Brazilian production is from alluvial concentrations near the town of Lencoes, in Bahia province (Stutzer and Eppler, 1935). Carbonado has also been reported from Parana province (Bétim, 1929), and a few stones have been received in shipments from Minas Geraes. Old descriptions (Couttolenc, 1892; Moissan, 1893) of the DeBeers Mine in South Africa mention small amounts of the mineral occurring there, and Ksanda and Henderson (1939) identified black grains from the Canyon Diablo meteorite as carbonado. The ultimate source of the carbonado reported by competent authorities in diamond shipments from French Equatorial Africa and Arkansas is in doubt, while all stones from Borneo which have been examined by Mr. Ball have been well-crystallized black gem stones, rather than aggregates.

A complete listing of reported occurrences of carbonado is difficult because of the rather confused nomenclature which exists for description of the subspecies of diamond. The terms used are often those applied by miners in one region to diamond aggregates which seem unusual to them; consequently, the terms are poorly defined and overlap at times. There exists a need for a critical analysis and revision of this nomenclature. "Bort" is dark-colored diamond occurring in rounded, poorly-crystallized grains which are translucent to opaque (Shipley, 1945); in the gem trade this definition is extended to all impure diamonds and even to fragments and powder of gem diamonds, provided that on account of their small size they are valueless as gem stones. Williams (1932, vol. II, p. 470)

uses bort as a general name for "granular crystalline" diamond, ranging from "phanero-crystalline to crypto-crystalline structure." Williams' work deals with South African occurrences, and is therefore an excellent reference for the terminology of that area: "Framesite" is an extremely fine-grained type of bort, in which the particles are so arranged that it is almost impossible to saw the material with the ordinary diamond saw. "Stewartite" is bort which Dr. J. C. Sutton (1928, p. 38) found to be slightly magnetic and polar because of the presence of intimately admixed magnetite. Stewartite is cindery-looking and minutely porous, with the low specific gravity of 3.45; it occurs in dull-gray to grayish black lumps in the Wesselton and Jagersfontein mines (Wagner, 1914, p. 142). Both framesite and stewartite thus have features in common with "carbonado," which is a Brazilian term for a more or less porous, fine-grained to dense aggregate of minute diamond particles, which are usually light brown individually. The dark gray to black color seen in aggregate is largely caused, therefore, by the small opaque particles of amorphous carbon, graphite, and various metallic oxides and more complex minerals which occur within and between the diamond individuals. Larger crystals of diamond sometimes are found in this fine-grained, black matrix. By applying a blowpipe flame briefly to a polished surface of carbonado, Fettke and Sturgis (1933) were able to distinguish grain boundaries more clearly, and to demonstrate that the toughness of the mineral was due not only to the fineness of the grain size, but also to a definite interlocking of those grains.

LABORATORY EXAMINATION OF SURUKUN SPECIMEN

A spectrographic analysis was kindly made by Dr. M. L. Fuller of the Research Division of the New Jersey Zinc Company at Palmerton, Pennsylvania. He reported Si present in moderate amount, faint lines of Al and Ti, very faint Fe and Ni lines, and extremely faint lines of Cu, Mg, and Be.

An x-ray pattern taken with a Debye powder camera, using iron radiation contained the 111- α , 111- β , 220- α , 220- β , 311- α , 311- β and 400- β lines of diamond. These 7 lines constitute the entire group of reflections for diamond using iron radiation. In addition, there were several extra lines corresponding to strong reflections in a reference pattern of quartz. Since the sample was prepared in an iron mortar rather than the agate mortar used for routine work, this impurity must have come from the carbonado itself. The presence of a quartz-family mineral is further verified by the amount of Si in Dr. Fuller's analysis, and by optical examination of fragments of a white crust which can be seen to fill minute cracks in the specimen. The aggregate extinction, pinkish color in parallel light,

and index $N = 1.530$ for these fragments, indicate that the crust is probably chalcedony. Unfortunately, this component was not present in sufficient quantity to furnish enough for an x -ray sample.

The material responsible for the black color of the specimen cannot be resolved into discrete particles under high magnification, does not appear as a prominent impurity spectrographically, and gives no lines in the x -ray pattern. It may be amorphous carbon. The compounds contributing Al to Ti to the spectrographic analysis are present in such minute amounts that they do not produce lines on the x -ray pattern. An intense darkening of the background of an x -ray pattern of carbonado, in comparison with that of a single crystal of diamond, was noted by Gerloch (1924). No such contrast was observed in the present study.

The specific gravity of the specimen is 3.412, considerably below the value 3.511 quoted for single blue-white diamond crystals (Dana, 1944, p. 147). The specimen has a visibly low porosity which may account for the slightly high value for carbonado. Due to the filling of existing openings with chalcedony, a properly corrected value might be slightly higher.

The aggregate nature of carbonado, recognized by its toughness and lack of well-defined cleavage directions, is further substantiated by x -ray powder patterns taken in this study. All samples were broken by impact on a steel plate, and the steel fragments were subsequently removed with a magnet. In reflected light the surface of the carbonado was seen to be composed of unit reflecting areas, which are not necessarily unit crystals, of an average diameter of slightly less than 0.02 mm. The natural diameter is so small that the grains lie within the particle size limit for x -ray powder photographs. Hence, the natural fineness of a grain of carbonado is assumed to be responsible for the smooth lines in the pattern. One reference pattern obtained by grinding a small diamond crystal had extremely spotty lines. Another, obtained by cleaning and screening abrasive residues from a grinding laboratory, was satisfactory.

The lattice constant for the material, calculated from a Debye powder pattern, is 3.558 Å. A published lattice constant for diamond (Ehrenberg, 1926) is 3.5595 ± 0.0010 Å. It should not be inferred, from the slight discrepancy between these values, that carbonado has a slightly smaller lattice constant than diamond. Greater precision in measurement would be necessary to yield definite information on this point. Within the experimental limits of the technique employed the two are the same.

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DOMESTIC SOURCES OF PIEZOELECTRIC CRYSTALLINE QUARTZ

HUGH H. WAESCHE*

An adequate supply of crystalline quartz of piezoelectric grade and size continues to be of fundamental importance to the U. S. Army Signal Corps. Current electronic development programs of the Armed Forces depend upon the use of quartz crystals in all applications where accurate frequency control is necessary. In peacetime this may not seem too significant, but in planning for possible national defense emergencies, an adequate supply of piezoelectric grade raw quartz is just as important as an adequate supply of some of the more publicized strategic minerals.

Prior to World War II, the Signal Corps accepted the use of quartz crystals for frequency control purposes in essentially all electronic communication, navigation and radar equipment operating in the audio and radio frequency spectra up to and including the ultra high frequency channels. Some equipments required a complement of 100 or more crystal units plus spares and replacements for satisfactory operation. As a result, over 70,000,000 crystal units were manufactured for the Army, Navy and Air Forces, requiring over 4,000,000 pounds of radio grade

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quartz, between January 1942 and V-J Day. Use of such a large quantity of crystal units was necessary in order to establish and maintain, with a minimum of effort, clear and definite frequency channels of greater stability than could be obtained by any other means. This policy was justified on the basis that quartz was without a peer as a frequency controlling element. Military and civilian uses of quartz in the field, as well as laboratory studies, have confirmed this premise and as of this date, no means of highly stable frequency control, superior to quartz, has been discovered. It appears certain that the demand for use of quartz for frequency control purposes will continue at a high level because its outstanding value in this service will be a strong consideration and determining factor in development and use of military electronic equipment.

One of the greatest difficulties in the past use of quartz has been that of supply. The only dependable source of acceptable raw material has been Brazil. During World War II, it was necessary to ship the quartz over difficult supply lines, including marine transportation subject to enemy naval attack. Late in 1942, this became such a serious problem that it was necessary to ship the quartz by air freight, which limited the quantity obtainable. That situation was alleviated somewhat by the clearing of the sea lanes through the Caribbean in 1943, but at no time since has this country been free of the necessity of stockpiling quartz for strategic purposes. "Quartz Crystal" has been listed invariably during the past two years as a "strategic mineral" on every public tabulation of minerals that must be stock-piled. Some relief from quantity requirements in the future may be obtained through design of equipment requiring fewer crystal units, use of substitutes for natural quartz, design of more dependable crystal units that would require less replacement, conservation of quartz through improved manufacturing methods, greater utilization of lower grade quartz, and design of crystal units utilizing less quartz. A program for conservation of this nature was initiated by the War Department, Office of the Chief Signal Officer in 1943, and was subscribed to throughout the duration of hostilities by all the agencies responsible for the use of piezoelectric grade quartz. This program resulted in an increased yield of eighty per cent per pound of quartz consumed. It is intended that this policy continue in effect insofar as Government uses are concerned.

Quartz is not the only piezoelectric crystalline material. Over one hundred and seventy-five substances have been reported by various investigators to have piezoelectric properties in varying degrees. Any crystal having no center of symmetry should be piezoelectric although many (such as cinnabar) are electrically conductive and therefore cannot be used for electronic frequency control purposes. Practically all the other

substances have various physical properties that make them unsuitable for frequency control applications. Three other minerals which offer promise for electronic, piezoelectric use are crystalline tourmaline, nepheline, and berlinite. However, none of these materials appear to occur plentifully in nature in suitable form. Tourmaline, for piezoelectric use, must be of the non-iron bearing variety. Nepheline and berlinite apparently do not occur in large, well formed crystals. The Signal Corps Engineering Laboratories would be interested in any information concerning the location and quantities of any of these minerals occurring in large, crystalline form, relatively clear and free from defects.

The Signal Corps has been so concerned over the future natural quartz supply for piezoelectric frequency control application, that it has launched a program for synthesis of substitute materials. Brush Development Company of Cleveland, Ohio, and Antioch College, Yellow Springs, Ohio, are well along on quartz synthesis. Edward Washken of Cambridge, Mass., is engaged in research for synthesis of nepheline and Baird Associates of Cambridge, Mass., is engaged in research for synthesis of tourmaline. The University of Minnesota and Squier Signal Laboratory of Fort Monmouth, N. J., are investigating the synthesis of berlinite. These projects (with the exception of Squier Signal Laboratory) are being sponsored by means of contracts with the Signal Corps Engineering Laboratories. The Naval Research Laboratories are making major contributions to piezoelectric crystal synthesis. Results to date have been gratifying but in no way affect the present Signal Corps desire to promote consideration for radio grade quartz wherever explorations of any kind are conducted in Central and North America.

It is well known by geologists, mining engineers, and mineralogists that quartz is one of the most abundant mineral constituents of the earth's crust; large quantities occur throughout Central and North America. Unfortunately, piezoelectric use of quartz is very exacting in its requirements, thus limiting usable quartz to only one of many varieties. It must be crystalline and must be essentially eye clear, free of impurities, physical defects and crystallographic variations, including twinning, within any given crystal. The dimensions of operating crystal plates, and manufacturing methods have limited the physical size of the quartz crystals heretofore used to a minimum of 100 grams by weight having a length parallel to the vertical crystallographic axis of at least two inches and a diameter, perpendicular to the vertical crystallographic axis, of at least one inch. Quartz of this size must exhibit at least one identifiable crystallographic face for economical use, although crystals over 200 grams can be economically processed whether "faced" or not. Obviously, the piezoelectric grade of this important mineral is rare in occurrence in

sizeable deposits. Limited, known sources in North and Central America have been confined largely to uneconomical deposits in Guatemala, Arkansas, and California. Usable crystals have been found singly or in very small quantities scattered throughout Central and North America and it is a reasonable geologic assumption that satisfactory sources, as yet undiscovered, may exist in these regions. Continued geologic exploration may be expected to reveal such sources; especially is this true when it is considered that much investigation of this nature remains to be done in some of the more remote or inaccessible localities (e.g., Alaska). Large deposits of piezoelectric grade quartz even in Continental United States may exist and this possibility cannot be dismissed.

Military and civilian officials of the Signal Corps have recognized and discussed the problems covered in the preceding paragraphs during the past several years. An active program on the part of the Signal Corps Engineering Laboratories calls for continuous liaison with the Geological Survey, Bureau of Mines, other Government organizations, including State Surveys, Geological and Mineralogical Societies, Educational Institutions and Mining Organizations. These groups, as well as individuals, are asked to be on the alert for sizeable bodies of radio grade quartz and to advise the Commanding Officer, Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey, of such findings. Signal Corps representatives will examine any North or Central American piezoelectric mineral source localities in coordination with the other interested Government agencies or groups indicated, if warranted. Quartz so located will be tested by the Signal Corps Engineering Laboratories for piezoelectric qualities. These Laboratories would also be interested in information regarding relatively large deposits of crystalline quartz of individual crystal sizes in the range of 30 to 100 grams.

PETROGRAPHY OF A SAMPLE OF BEDROCK FROM A DEEP WELL
AT ROCKAWAY PARK, LONG ISLAND, NEW YORK¹

CLAUDE M. ROBERTS

Further evidence as to the position and character of the bedrock of Long Island has been brought forth as the result of a recent petrographic study of a sample of the bedrock from the drilling of a deep well beneath Rockaway Park.

In 1939, one of two deep wells, Q 1030, drilled by the Department of

¹ Published by permission of the Director of the Geological Survey, United States Department of the Interior.

Water Supply, Gas and Electricity of the City of New York, penetrated something over 70 feet of the bedrock from a depth of about 970 feet below mean sea level at Rockaway Beach Boulevard and Beach 111th Street, Rockaway Park, N. Y.

A solid piece of the rock core from this well between the depths of 1,039 and 1,046 feet was selected for petrographic study.

The rock sample has the general appearance of a medium-grained, even-textured granite in which light-pink and gray feldspars and glassy quartz are discernible to the eye and predominate. There are also small flakes of muscovite, biotite, and other mica-like minerals, a few small red garnets, and brassy cubes of pyrite in very small amounts. Thin coatings of a clay-like substance and iron stains appear in some areas.

A thin section of the rock core was prepared and examined under the petrographic microscope. The rock is granitic in texture, the grains being dominantly 1 to 4 mm. across. The essential constituents are subhedral alkali feldspars and anhedral quartz.

Potash feldspar is the predominant mineral, comprising about 65 per cent of the rock. The grains are commonly subhedral to anhedral, and exhibit twinning. Oligoclase comprises only about 1 per cent of the rock; the grains are small (generally about 1 mm. across), anhedral, and polysynthetically twinned.

Quartz constitutes about 25 per cent of the rock. It appears as irregular grains of various sizes and is commonly interstitial to the feldspars. It is usually clear and exhibits wavy extinction; a few grains contain minute dark inclusions.

The minor minerals comprise about 10 per cent of the rock. The micas muscovite and biotite are both present as small scattered flakes. The biotite is pleochroic in pale brown to green. Small, slender prisms of apatite are present throughout the feldspars; many of the prisms are jagged and deeply embayed. Small, nearly opaque iron-bearing garnets are present; most are anhedral and many are hardly distinguishable because of alteration to a greenish chlorite.

The granite shows slight alterations, probably by deuteric processes and weathering. No evidence of regional metamorphism was found. The relation of this granite to other recognized rock units in the general area is not known.

Acknowledgment is made to the City of New York, Department of Water Supply, Gas and Electricity, which furnished the core samples to the U. S. Geological Survey for this study. An entire suite of samples was examined by the U. S. Geological Survey in connection with the joint ground-water studies being carried out on Long Island with the New York State Water Power and Control Commission.

NOMENCLATURE IN MINERALOGY: THE BASIS FOR NEW
MINERAL NAMES

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In a recent note, Mr. Ernest E. Fairbanks¹ suggests that mineralogists use the prefix "micro" in order to indicate, as we understand it, that the "new mineral" may not be a new mineral at all. Mr. Fairbanks, furthermore, implies that some mineralogists are in favor of introducing new mineral names on the basis of inadequate descriptions provided the prefix "micro" is affixed. These opinions seem to bear upon the fundamental nomenclature of mineralogy and therefore warrant further consideration.

It is self-evident that the existence of a physical entity, such as a mineral, is independent of the methods of observation. Consequently, mineralogists should be quite reluctant to assign a mineralogical name embodying the prefix "micro" because the sole evidence for the existence of the substance is based upon microscopic observations. A mineral name should not encompass within its definition any particular method for determination.

On the other hand, the proof of the existence of mineral substance is dependent upon the methods of observation. The evidence for its existence must be conclusive. Mineralogists should be emphatic in the rejection of careless and inadequate work, particularly with regard to the introduction of new mineral names where the evidence is inconclusive. Any modern description of a new mineral should include accurate and nearly complete determinations of the following:

- I. *Chemical properties*—complete chemical analysis of highly purified material, determination of the stoichiometric ratios of oxides, solubility, etc.
- II. *Optical properties*—the principal refractive indices (if transparent or translucent, otherwise the anisotropism), orientation of optic axes, color, pleochroism, etc.
- III. *Structural properties*—crystal system and class, cleavage, specific gravity, hardness, unit-cell dimensions, space group, etc.

Almost complete data are required in order to demonstrate that a mineral has not been previously described. Minerals that have been named solely on the basis of incomplete determinations of their optical properties and erroneous or incomplete chemical data should be disregarded by mineralogists and papers containing incomplete descriptions should be rejected by editors.

A mineral name is merely a useful label which serves to denote a chemical compound of natural origin having certain crystallographic and

¹ *Am. Mineral.*, **32**, 683 (1947).

physical properties. If the properties are not described with sufficient accuracy and completeness to permit systematic classification, the name serves no useful purpose whatsoever.

Furthermore, in the description of new minerals, authors should demonstrate the crystallographic and chemical relationships of any new species to other minerals. Adherence to this practice will not only aid in the recognition of the particular mineral species when discovered at another locality with isomorphic variants, but will aid in the formulation of more significant geological and geochemical principles.

Unrecognizable, unidentifiable, or unknown mineral substances are frequently encountered by skilled mineralogists and petrographers. This fact does not reflect on the intelligence or capability of the mineralogist or petrographer; he should frankly state that the mineral was not identifiable by the methods employed or during the time available. Nothing is gained by adding another poorly defined term to the literature. Prefixing of "micro" makes the situation worse rather than better. Well-authenticated mineral names beginning with "micro" already exist, including microcline, microlite, and microsommite. The nomenclature of mineralogy is sufficiently complex without unnecessary additions to the "conspiracy in jargon."

UNIT CELL AND SPACE GROUP OF PIRSSONITE

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The unit cell and space group of pirssonite have been determined from a series of Buerger precession photographs taken from a broken fragment obtained by crushing a crystal from Searles Lake, California. These crystals from the type locality were described by J. H. Pratt¹ as orthorhombic hemimorphic; his data are checked by the x -ray study. The results of this study are tabulated below. Zero, first and second levels were photographed normal to both the a and b axes. The patterns with their characteristic extinctions provided an unequivocal determination of the space group. Calibration of the camera with a quartz crystal indicates that the values for the cell edges are accurate to 0.02 per cent. They are calculated from the wavelength (CuK_α) recently reported by Bragg in absolute Angstrom units.

Mineral: pirssonite, $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$.

Locality: Searles Lake, California.

Crystal class: orthorhombic hemimorphic, $C_{2v}=2mm$.

¹ Pratt, J. H., *Am. Jour. Sci.*, ser. 4, **2**, 126 (1896).

Cell dimensions:

$$a_0 = 11.32 \text{ A. U.}$$

$$b_0 = 20.06$$

$$c_0 = 6.00$$

$$a:b:c$$

$$X\text{-ray} \quad 0.5643:1:0.2991$$

$$\text{Pratt} \quad 0.5662:1:0.3019$$

Lattice and space group: face-centered, $C_{2v}^{19} = Fdd2$; 8 molecules $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ per cell.

Density: calculated, 2.367; measured (Pratt), 2.352.

This work was carried out as part of a program to complete crystallographic data for the 7th edition of Dana's *System of Mineralogy*. The second volume of this work is now in preparation at the Department of Mineralogy, Harvard University, under the direction of Professor Clifford Frondel, who kindly loaned the material for these measurements. Acknowledgments go to Professor A. von Hippel of the Laboratory for Insulation research, Massachusetts Institute of Technology, who provided the x-ray diffraction facilities.

NOTE ON SCHIRMERITE

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By making use of A. Harcourt's well-known tables¹ for the identification of ore minerals by means of x-ray powder photograms the author occasionally identified a mineral as *schirmerite*, $\text{PbAg}_4\text{Bi}_4\text{S}_9$. This was unexpected as a spectro-chemical analysis had not shown any presence of bismuth and only traces of silver and lead. The agreement between the d -values and the intensities from the table and from the x-ray pattern was perfect. A closer inspection showed, however, that the d -values fit an isometric structure with a cube length of 10.36 kX. All the 27 lines, except one ($d = 2.82$ kX) having an intensity of only 0.2, can be indexed according to the criteria of the space-group $T_d^3 - \bar{1}43m$. So it must be concluded that the specimen used by Harcourt was a member of the tetrahedrite group. It may be pointed out that the specimen used by him was not obtained from the original schirmerite locality.

¹ Harcourt, G. Alan, *Am. Mineral.*, **27**, 63 (1942).

The Annual Meeting of the Society for Experimental Stress Analysis will be held at The Roosevelt Hotel, Pittsburgh, Pennsylvania, on May 27, 28, 29, 1948. Inquiries may be addressed to the Society for Experimental Stress Analysis, P. O. Box 168, Cambridge 39, Massachusetts.

INTERNATIONAL UNION OF CRYSTALLOGRAPHY

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The first Congress of the International Union of Crystallography will be held at Harvard University from July 28 to August 3, 1948. The Mineralogical Society of America is one of the member societies in the United States. Members of The Mineralogical Society wishing to attend the Congress should notify Professor Clifford Frondel, 12 Geological Museum, Oxford Street, Cambridge 38, Massachusetts, stating whether they are coming alone or accompanied by someone and whether or not hotel reservations should be made.

Specimens of stylotypite are being systematically studied by Charles Milton, U. S. Geological Survey, Washington, D.C. He requests that any specimens so labelled be loaned to him for study; they will be returned intact (unless permission is given to remove a few milligrams for X-ray study) with, it is hoped, either verification of the label or a correct identification.

Herbert P. Whitlock, curator emeritus of minerals and gems, American Museum of Natural History, and past president of The Mineralogical Society of America, died February 22, 1948, at the age of 79 years.

MINERAL SPECIMENS

Loellingite—Paulus Vein, Loelling, near Hüttenberg, Carinthia. Bright silver gray fibrous masses with siderite. $2\frac{3}{4} \times 3\frac{3}{4}$ ", \$15.00, $3 \times 3\frac{1}{4}$ ", \$10.00, $2\frac{3}{4} \times 3\frac{3}{4}$ ", \$8.00, 2×3 to $1\frac{1}{2} \times 3\frac{1}{4}$ ", \$6.00, \$5.00, \$4.00, \$3.00, 2×2 " to $1\frac{1}{2} \times 2\frac{3}{4}$ ", \$2.00, \$1.50.

Gersdorffite, gray xline masses with Chalcopyrite, Mühlbach, near Bischofshofen, Salzburg. $3\frac{1}{4} \times 3\frac{3}{4}$ ", \$9.00, 2×3 " to 2×2 ", \$3.00 and \$2.50.

Blue Halite—Stassfurt, Prussia. Cleavages colored deep prussian blue. $2 \times 2\frac{1}{2}$ ", \$4.00 and \$3.50, $1\frac{1}{4} \times 2$ " to $1\frac{1}{2} \times 1\frac{1}{2}$ ", \$2.50.

Topaz Crystals. Teofilo Otoni, Minas Gerais, Brazil. Magnificent clear crystals of museum quality. Crystals are $4\frac{3}{4} \times 7 \times 9\frac{1}{2}$ " at \$200.00, $5\frac{3}{4} \times 5\frac{3}{8} \times 5\frac{3}{16}$ ", \$145.00, $4\frac{5}{8} \times 4\frac{7}{8} \times 3\frac{1}{8}$ ", \$40.00. Plus 20% F.E. Tax. Other sizes and prices available on request.

Quartz crystals enclosing blue Tourmaline and Helvite. Governador Valadares, Minas Gerais, Brazil. These clear quartz crystals contain minute honey-colored tetrahedrons of helvite and capillary blue tourmaline crystals. Sizes average $4\frac{1}{2} \times 7$ " to 3×4 ", \$5.00 and \$4.00, 3×6 to $2 \times 3\frac{1}{2}$ ", \$3.50 and \$3.00, 2×3 to 2×2 ", \$2.50, \$2.00 and \$1.50. Plus 20% F.E. Tax.

Baddeleyite—Pocos de Caldas, Minas Gerais, Brazil. Greenish-gray fibrous masses with Zircon and rock. Specimens average $3\frac{1}{2} \times 3\frac{1}{2}$ to $2\frac{1}{2} \times 4$ ", \$8.00, $2\frac{1}{2} \times 3$ ", \$6.00 and \$5.00, 2×3 " to 2×2 ", \$4.00, \$3.50, \$3.00 and \$2.50, 2×2 " to $1\frac{1}{2} \times 2$ ", \$2.00 and \$1.50.

Magnesite—Serra das Eguas, Baia, Brazil. Large colorless cleavages. $3 \times 2\frac{1}{2} \times 1\frac{1}{2}$ ", \$7.50, $2\frac{1}{2} \times 2\frac{1}{2} \times 2$ ", \$7.50, $2\frac{1}{8} \times 2\frac{1}{2}$ ", \$4.00, 2×2 " to $1\frac{1}{2} \times 1\frac{1}{2}$ ", \$3.00, \$2.50, \$2.00 and \$1.50, $1 \times 1\frac{1}{2}$ " to 1×1 ", \$1.00, \$.75, and \$.50.

Columbite—Governador Valadares, Minas Gerais, Brazil. Choice black tabular masses, showing some crystal faces. Specimens average $4 \times 4\frac{1}{4}$ ", \$20.00, $4\frac{1}{2} \times 2\frac{1}{2} \times 2$ ", \$17.50, $3\frac{1}{4} \times 3\frac{5}{8}$ ", \$16.00, $4\frac{3}{4} \times 3$ ", \$15.00, $2\frac{3}{4} \times 3 \times 2$ ", \$14.00, $2\frac{1}{4} \times 4$ to $1\frac{3}{4} \times 2\frac{1}{2}$ ", \$8.00, \$7.50, \$6.00 and \$5.00, $1\frac{1}{2} \times 2$ " to $1\frac{1}{4} \times 1\frac{1}{4}$ ", \$4.00, \$3.00, \$2.50, \$2.00, \$1.50 and \$1.00.

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